~~NASA~~ CR 151332

(NASA-CR-151332) PRECISION MULTIBAND VIEWER STUDY (Long Island Univ.) 140 p N77-77075

Unclas
00/35 24465

SCIENCE ENGINEERING RESEARCH GROUP

C. W. POST RESEARCH CENTER
LONG ISLAND UNIVERSITY

LONG ISLAND UNIVERSITY
SCIENCE ENGINEERING RESEARCH GROUP
C.W. POST CENTER
GREENVALE, NEW YORK

SERG TR-14

PRECISION MULTIBAND VIEWER STUDY

NAS 9-9489

Jerome Libby
Edward Yost

Prepared for the National Aeronautics and Space Administration under contract #NAS9-9489 with the Manned Spacecraft Center.

ABSTRACT

The Precision Multiband Viewer Study was prepared by the Science Engineering Research Group, Long Island University, in accordance with the requirements of Exhibit "A", Statement of Work for "Precision Multiband Viewer Study", contract NAS 9-9489.

The Precision Multiband Viewer, hereafter referred to as PMV, will be used for the screening and precision analysis of multiband photographic imagery obtained with multiband photographic systems to be used by the NASA. The PMV will be installed at the Manned Spacecraft Center and will be available for use by the earth resources user agencies and Principal Investigators. The PMV will be designed to accommodate, as possibile multiband imagery obtained from other camera systems.

The objective of the PMV study was to define and develop design criteria and preliminary specifications which will enable NASA to procure a suitable viewer with a minimum of design expense consistent with the desired and necessary level of performance. To accomplish this the study was organized into nine (9) tasks as follows:

- Section 1- Preliminary Study Criteria & Pre-Registration Concept
- Section 2- Preliminary Findings-"Feasibility of Constructing a PMV to Handle 5" & 70mm Photography". (NASA letter, ref.TF-6, 6 June 1969)
- Section 3- Determine & Evaluate Existing State-of-the-Art of all Available Apparatus & Techniques for Achieving Color Presentations from Multiband Photography
- Section 4- Discussion of Projection Lens Criteria for PMV
- Section 5- Projection System Design Criteria
- Section 6- Registration Criteria & Error Analysis
- Section 7- Preliminary Specification, RG-321-S, for PMV
- Section 8- Acceptance Test & Calibration Specification, RG-321-ATS, for PMV
- Section 9- Conclusions & Recommendations

Sections 7 and 8 represent the required outputs from the PMV study in accordance with the Work Statement for Contract NAS 9-9489. Section 2 represents the preliminary findings in response to a NASA letter request, ref. TF-6, dated 6 June 1969. Section 9 presents further discussion, approaches and design analyses relating to the advantages of the Pre-Registration Concept briefly introduced in Section 1.

It is recommended that further study be conducted to further analyze the Pre-Registration Concept, and that a breadboard model be constructed to demonstrate the feasibility of this concept, which can be very advantageous for multiband photographic imaging systems.

PRECISION MULTIBAND VIEWER STUDY-PMV

(CONTRACT NAS9-9489)

1. INTRODUCTION

1.1 Statement of the Problem

The Precision Multiband Viewer Study was organized in accordance with the requirements of Exhibit "A", Statement of Work, Contract NAS9-9489 for Earth Observations Division, NASA/MSC, Gary L. Kraus, Technical Monitor, as shown in the Flow Diagram of Figure 1.1. The ultimate objective is to define and develop design criteria and preliminary specifications which will enable NASA to procure a suitable viewer with a minimum of design expense consistent with the desired and necessary level of performance.

1.2 Preliminary Study Criteria

Pre-Registration Concept

Figure 1.2 shows the Functional Flow-Diagram of the Pre-Registration Concept wherein it is considered that the basic problem of precisely registering the four multiband images, at their specified locations, is not accomplished in the Viewer but in a separate high precision projection printing device having an adjustable film gate. The registration will be accomplished by unskilled personnel, through the use of easily handled and understood alignment adjusting mechanisms and controls. After the image content of each film frame has been adjusted and registered to the reticles of the superimposed image, it is recorded in its exactly desired location on the duplicating film roll.

The pre-registration can be accomplished as shown in Figure 1.3, by projecting each image on to a projection screen mask, incorporating adjustable reticles. Depending upon the subject matter of the film frames, select and identify at least four significant key points and

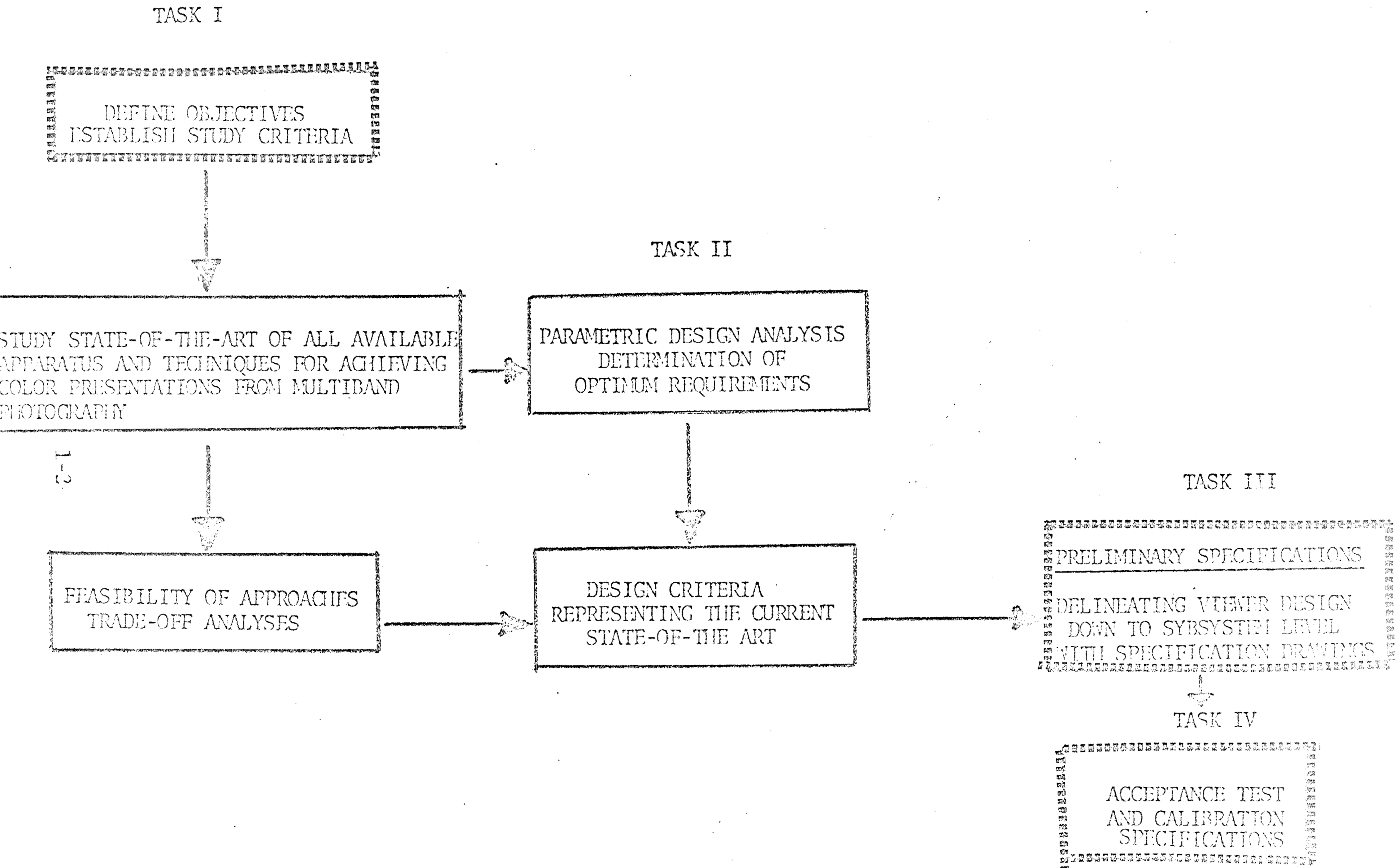


FIGURE 1.1
PRECISION MULTIBAND VIEWER STUDY-FLOW DIAGRAM

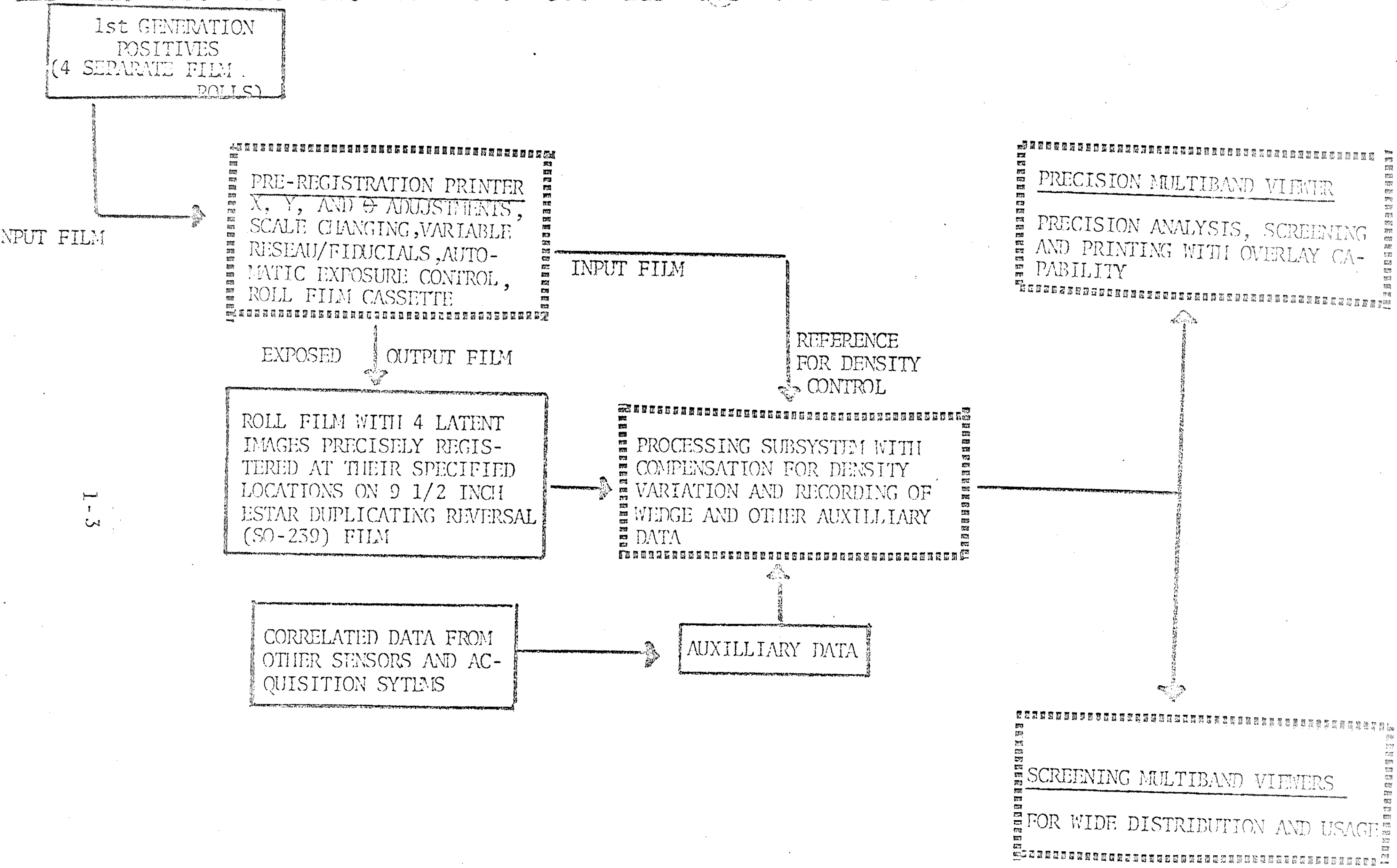


FIGURE 1.2

FUNCTIONAL FLOW DIAGRAM

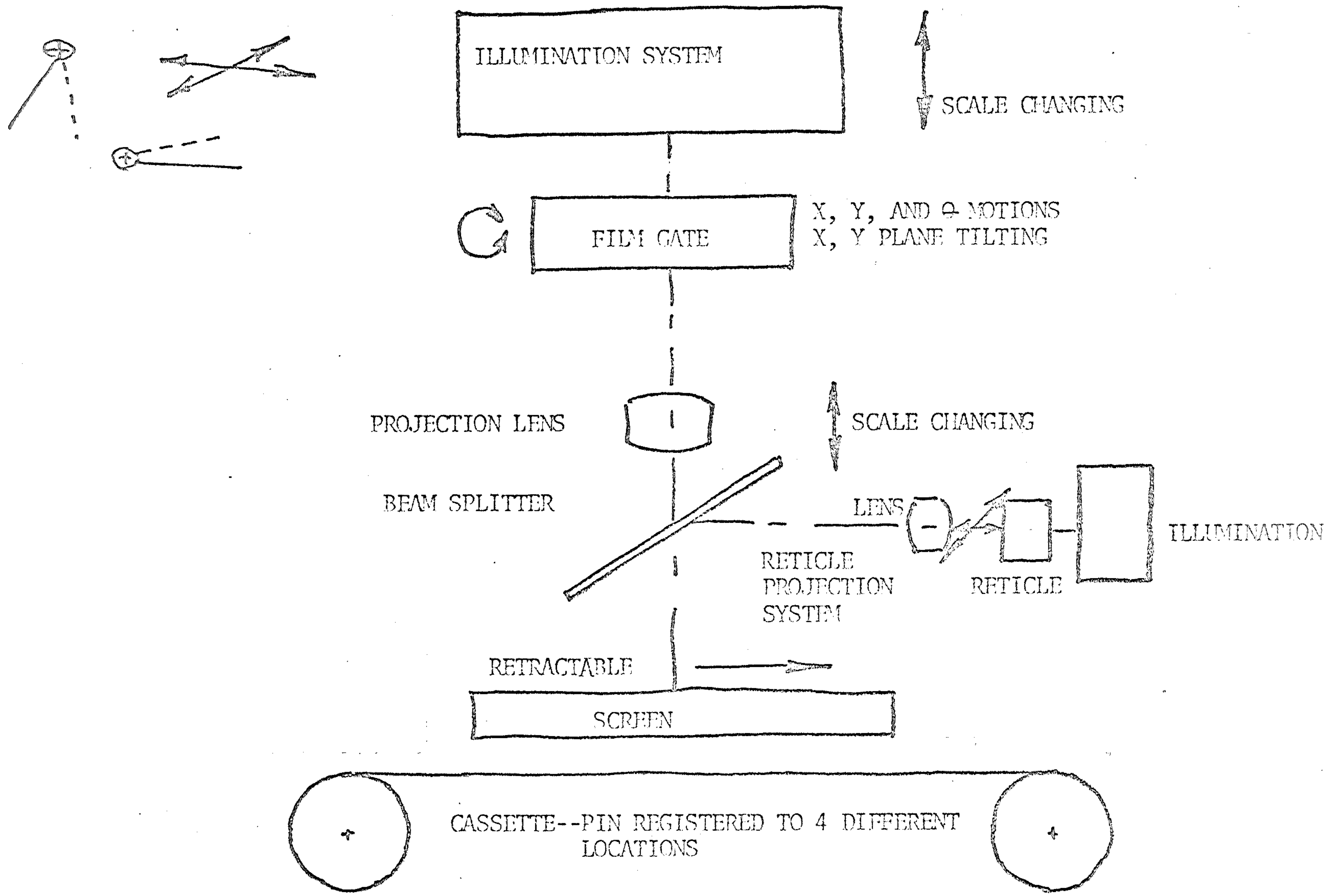


FIGURE 1.3

PRE-REGISTRATION CONCEPT

precisely align the screen reticles on to these images using a microscope or magnifier for aided viewing. This would be done with a Roll Film Cassette in position 1.

After recording film frame #1, the Cassette is removed from the optical path and film frame #2 is projected, adjusted and aligned until the same significant key points, of this second similar but spectrally different piece of imagery, are exactly aligned to the screen reticles located from the first. This procedure is repeated for film frames #3 and #4. The single highly precise and versatile film gate has provision for easily controlled X, Y and θ motions of the film frame, tilt changing, distortion removal, or if needed, variable scale changing. Automatic exposure control will be provided so that the easily removable roll film cassette with each latent image exactly located, can be readily processed. The four multiband 70 mm x 100 ft. film rolls are mounted on a carriage which indexes each film roll on to the single optical projection system's axis. Each frame, of each film roll, would occupy the same location on the 9 1/2" wide cut film which contains a set of 4-70 mm images, one for each roll.

It is contemplated that the auxiliary data, correlated from other sensors and acquisition systems, will be input at the processing sub-system as shown in Figure 1.2. Since the input film is specified as a positive material, the 9 1/2 inch wide estar base duplicating film has been specified as SO-239, a reversal film, so that positives will be made available to the film viewers without any subsequent operations. In the event that the input film is negative, then 2430 estar duplicating film can be used. The pre-registration concept is ideally suited for the utilization of two types of multiband viewers, as shown in Figure 1.2. The objectives of "screening" and "precision analysis" are best served by separate devices rather than combining the functions required for these different objectives in one particular designed multiband viewer.

2. PRELIMINARY FINDINGS;

FEASIBILITY OF CONSTRUCTING A PRECISION MULTIBAND VIEWER TO HANDLE 5 INCH AND 70 MILLIMETER PHOTOGRAPHY

2. 1. INTRODUCTION

The purpose of this investigation was to determine the feasibility of constructing a viewer to handle 5 inch and 70 mm frame multiband photography, as per paragraph 2 of NASA letter, ref. TF 6, dated June 6, 1969. A discussion on the techniques and problems involved in designing such a viewer is given.

The investigation was conducted within two basic phases. In phase A, the feasibility criteria and techniques for evaluating this criteria was established. In phase B, the feasibility analysis was conducted and attempts for performing quantitative, as well as qualitative, analysis are presented and discussed.

2. 2. FEASIBILITY APPROACH

In establishing criteria for feasibility and techniques for evaluating these criteria many considerations come to mind. Some of these considerations, such as; will it work?, will it be useful?, are difficult to quantitize. Other considerations such as cost, size, weight, power, etc., can be more quantitatively determined, however, are not significant by themselves unless appropriate "weighting factors" are applied.

Prior study activity has been directed toward studying the state-of-the-art of all available apparatus and techniques for achieving color presentations from multiband photography. Some of this activity indicates some novel methods for recording and retrieving full color images with panchromatic black and white film, as well as a wide gamut of additive color viewers having many varied characteristics and design criteria.

Feasibility can not be determined by proving whether it will work or not. Other factors must be entered into the evaluation and the significance of all these criteria must be assessed and related to the specific objectives. Since the specific objectives themselves are not so clearly defined, and may even change significantly with time, an attempt was made to conduct this investigation in an orderly and objective fashion so that the data developed and presented will still be valuable and useful even with changing objectives.

Since "feasibility" was the prime basis of this investigation, it follows that heavy emphasis will be placed upon what is meant by feasibility. Feasibility, for this investigation, must relate to more than the quality of just being possible. It must place more emphasis upon practicability. Since this too might be defined differently by different individuals, this investigation will discuss and explain each criterion selected to avoid possible confusion or perhaps an unscientific evaluation.

2.3. ESTABLISH FEASIBILITY CRITERIA

Some of the more pertinent feasibility criteria are presented below:

- -Functional suitability and usefulness
- -Performance capability
- -Versatility and flexibility

- Cost factors
- Reliability
- Maintainability
- Ease of operation and human factors
- Training requirements
- Logistics
- Size and weight
- Power and cooling

The order of presentation does not necessarily relate to the level of importance.

2.3.1 Functional Suitability and Usefulness

The functional suitability and usefulness is the most significant of all the feasibility criteria. In order to effectively evaluate this most significant requirement, a thorough knowledge of all the "User's" needs are required. Since this is not readily available, consideration can be given to some of the more typical and generalized factors affecting projection viewing equipment of this nature.

Does the additional capability of handling 5 inch film, as well as 70 mm, help or hinder the photo interpreter in his primary task of extracting information from the multiband imagery? Will the larger format reduce the scanning time for searching the film roll? Is registration of the superimposed imagery more precise or easier to obtain? Is the resolution of the imagery sufficiently better and more useful to the interpreter in performing his analysis? What are the advantages in illumination and control of illumination? Is the illumination just as even for the 5 inch film gate? Are the distortions greater due to the greater angular coverage required for the 5 inch film? Does the correlated larger screen size for 5 inch film degrade the ease of operation, location of controls, and human factors capability? Does the increased range of film adjustment require a variable speed drive mechanism in order to cover a greater range with the same degree of accuracy? Table 2-1 presents the various parameters which come into consideration and a means for comparing these criteria.

TABLE 2-1

FUNCTIONAL SUITABILITY CRITERIA

Parameters to be Considered	70mm Viewer	5 inch & 70mm Viewer
Format (Gate)	2 1/4"x2 1/4"	4 1/2"x4 1/2"
Coverage	Half Cov.	Twice
Resolution	100 LP MM	60 LP MM
Projection lenses F.L	8 1/4" & 12"	17 3/4" & 20"
Distortion	Less	Greater
Magnification	3X & 6X	3X & 6X
Angular Coverage	Same	Same
Field Curvature	Less	Greater
Registration	5 microns	8 microns
Illumination Level	600' Lamberts	150' Lamberts
Eveness of Illumination	10% falloff	20% falloff
Dimming Control	Simple	More Complex
Film Transport	Less Inertia	More Inertia
Film Flattening	Same	Same
Film Guiding	Easier	More Acute
Range of Positioning Adjustments	Simple	More Complex
Auxiliary Displays	Feasible	Limited Feasibility
Printing & Reproduction	9 1/2" x 9 1/2"	9 1/2" x 9 1/2"
Overlay Capability	Limited	Greater
Screen Size	15" x 15"	30" x 30"

2.3.2 Performance Capability

This criteria is concerned with the ability of the specific subsystems of the two viewers to perform in accordance with their specified design criteria. That is, what is the capability of the 70mm Viewer, or the 5 inch and 70mm Viewer, to repeatably provide it's specified resolution value of 150 lines per mm?, of 30 foot-lamberts, ± 10 %?, etc. It does not refer to the MTBF* of the Reliability Criteria.

2.3.3 Versatility and Flexibility

This criteria refers to the ability of each specific Viewer to accommodate modifications, changes and updating for future growth or capacity. It reaches into the future where it would be expected that greater functional performance would be imposed on Precision Multiband Viewers as the technology advances. The exact nature of these expected changes can not be stated at this time and speculative considerations can not be reasonably evaluated. However, the capability for this criteria can be evaluated on the basis of knowledgeable projection viewer design considerations and this factor can be applied in the resultant decision making matrix.

2.3.4 Cost Factors

In the real practical world we live in, the cost factors are underlying almost every pertinent decision we make. The criteria of cost presents a simple numerical technique for any feasibility determination. The emphasis placed upon this criteria must also reflect the current

* (mean time between failures)

economic conditions which exist at the particular time. The application of appropriate "weighting factors" permit this quantitative criteria to be applied and related to technical criteria.

In addition to the direct costs associated with the specific viewing instrument, other meaningful cost data should be accounted for; for example:

- -cost of training
- -cost of replaceable and spare parts
- -cost of maintenance and support effort over some typical viewing instrument life span.

2.3.5 Reliability & Maintainability

The reliability and maintainability criteria are reflected by the relative degree of simplicity or complexity pertinent to the two viewers. However, it should be noted that a viewer with a high maintainability would generally not require a high reliability. The criteria evaluation should also consider that both viewers have similar design criteria. That is, they both should have manual over-rides for a motorized film transport design. The determination of MTBF and MTTR* provide easy relative quantitative assessment of these feasiblity criteria.

2.3.6 Ease of Operation & Human Factors

Ease of operation and human factors are perhaps the most subjective and most disputable criteria upon which to base an evaluation, since they are so strongly influenced by personal prejudice. Yet, they are unknowingly strong influences in forming the basis of whether or not

*(mean time to repair)

the instrument "will work" or be useful in meeting it's functions or even in attaining its specified performance. The interplay of the many control functions for these particular types of projection viewers, with all their micrometric precision adjustments and expanded dimming controls, indicate that this criteria must have strong value in the overall evaluation.

2.3.7 Training Requirements & Logistics

Training and Logistics relate to the availability of materials and personnel. The readiness with which many viewer parts may be made available from inventory and the availability of trained opertors and maintenance personnel are extremely important. The degree of complexity exhibited by a viewer determines the level of training required for its use. These considerations are evidently involved with less significant criteria and should be weighted accordingly.

2.3.8 Size, Weight, Power and Cooling

The significance of these criteria is also governed by the specific objectives of the users. For this investigation, it was assumed that there are no exacting requirements such as involving similar photo interpretation equipment used for defense activities. However, the equipment might still have to fit through doorways and be used in facilities having light floor loading, limited power and cooling capabilities.

2.3.9 Feasibility Evaluation Decision Matrix

A sample of a Feasibility Evaluation Decision Matrix is shown in

Figure 2-1. With the appropriate application of weighting factors based upon the specific objectives and requirements of the users, quantitative values can be applied to formulate an effective decision as to the feasibility of constructing a viewer to handle both 5 inch and 70mm film.

FIGURE 2-1

SAMPLE FEASIBILITY EVALUATION DECISION MATRIX	FUNCTIONAL SUITABILITY & USEFULNESS	PERFORMANCE CAPABILITY	VERSATILITY & FLEXIBILITY	COST FACTORS	RELIABILITY	MAINTAINABILITY	EASE OF OPERATION HUMAN FACTORS	TRAINING REQUIREMENTS	LOGISTICS	SIZE & WEIGHT	POWER & COOLING
PRECISION MULTIBAND VIEWER											
FOR 70mm FRAME PHOTOGRAPHY	* 1	4	4	5	4	4	4	4	5	5	5
FOR 5 INCH & 70mm FRAME PHOTOGRAPHY	* 5	2	2	1	2	2	2	2	1	1	1

5 = Best, 4 = Better, 3 = Equal, 2 = Poorer, 1 = Poorest

* Weighting factors should be applied, depending upon importance and relationship to the specific objectives.

3. Determine And Evaluate Existing State-of-the-Art of All Available Apparatus and Techniques for Achieving Color Presentations from Multiband Photography

3.1. Purpose

The purpose of reviewing existing state-of-the-art apparatus and techniques for achieving color presentations from multiband photography is to determine those functions and parameters best suited to the objectives of the PMV, as described in the work statement for contract NAS9-9489. In this review we have eliminated those multiband or multispectral applications which did not have the objective of achieving additive color presentations, such as the nine lens system developed by Itek. We have also reviewed the related technique of the multiple Image/Color Retrieval Viewer-Printer of Technical Operations but believe it has resolution limitations and considered its optical multiplexing technique as not being compatible with our objectives.

3.2. Parameters

The results obtained from a thorough study of available additive color viewers is tabulated in Table 3-1. This table compares the parameters and design criteria which define this type of equipment. The data was gleaned from technical reports, manuals and handbooks and specifications as referenced in Appendix A. The viewer parameters enumerated were selected to provide comprehensive correlated data for comparison so that the PMV design criteria, resulting from the study and analysis, can be more readily evaluated. Table 3-1 does not include all detail de-

VIEWER / PARAMETERS	[illegible] ADDITIVE COLOR VIEWER-PRINTER (A.F. AVIONICS LAB.)	[illegible] ADDITIVE COLOR VIEWER (GEOLOGICAL SURVEY)	[illegible] MULTIBAND ADDITIVE COLOR VIEWER SPECIFICATION	[illegible] MULTISPECTRAL FILM VIEWER	PRECISION MULTIBAND VIEWER (PMV) SPECIFICATION
A- MAGNIFICATION	8X(7.8X)	5X, 10X & 20X +3X MAGNIFIER	2X, 4X & 8X	3X	3X & 6X PROJECTION +4X MAGNIFIER & 2X-8X MICROSCOPE
B- NO. OF CHANNELS FILM SIZE & CAPACITY	4 70MM X 100FT ROLLS	3 ADDITIVE + 1 REF. 70MM X 100FT ROLLS	4 70MM-5"WIDE X 250FT. ROLLS	4 ON SINGLE FILM 9 1/2" WIDE X 400FT ROLL	4 70MM X 250FT. ROLLS
C- FILM GATE (FORMAT)	1" X 1" CENTER PORTION	55MM	4 1/2" X 4 1/2"	2 1/4" X 4"	2 1/4" X 2 1/4"
D- FILM FLATTENING	VACUUM HOLD-DOWN WITH FILM LOOPS	GLASS PLATENS	OPTICALLY FLAT GLASS PLATES UNIFORMLY TRANSMITTING 4000-7000 ° A	GLASS PLATENS	GLASS PLATENS
E- SCREEN SIZE & MATERIAL	8"X 8"- MAGNESIUM CARBONATE GROUND GLASS AND KODAK TRANSLUCENT PLATE	15" X 15" (2)	18" X 18" (45°VIEWING) AS REQUIRED	7" X 13" WHITE POLACOAT LENSCREEN	15" X 15" AS REQUIRED
F- RESOLUTION	171 L/MM AVERAGE AT GATE FOR FOUR CHANNELS	(DEPENDS ON FILM)	15AWAR L/MM AT 8X ON SCREEN	15 L/MM AT SCREEN	100 L/MM, MINIMUM AT GATE
G- REGISTRATION		80-90% OF THE 55MM FORMAT	±.005MM ACROSS ENTIRE FORMAT	± .1MM	TO SUIT RESOLUTION(ABOVE) OF SUPERIMPOSED IMAGE (5 MICRONS)
H- ILLUMINATION & DIMMING CONTROL	NEUTRAL DENSITY FILTERS, CLA 500 WATT TRU-FOCUS, ± 5% UNIFORMITY 550 FT. LAMBERTS WITH 1 EACH FILTER	1000 WATT LAMPS (CTT) VARIAC CONTROLLED BRIGHTNESS	400'-LAMBERTS,±10% AT 2X; 200'LAMBERTS,±10% AT 4X; 175'-LAMBERTS,±10% AT 8X: 3200°K COLOR TEMP.0-100%VARI.@SCREEN	200 WATT, 3200°K LAMPS FOR BRIGHTNESS AND SATURATION 50-100% DIMMING	600 FT. LAMBERTS FOR SUPERIMPOSED IMAGE WITH ONE OF EACH FILTER TYPE IN GATE
I-FILTERS	CORNING 5543 (BLUE) CORNING C-2412 (RED) WRATTEN 58 (GREEN)	47A, 25 & 58	WRATTEN # 47, 58 & 25A	47A, 25 & 58	DOMINANT WAVELENGTHS OF 473NM (BLUE), 540NM (GREEN), 615NM RED.
J-IMAGE POSITIONING	X, Y & θ + SCALAR CHANGES	X, Y & θ + PERPENDICULARITY IN X AND Y PLANES	X, Y &θ (±5°)	X & Y FOR EACH LENS ROTATION FOR FILM	X,Y,Z & θ
K- PROJECTION LENSES	8.25"f/5.6 SCHNEIDER COMPONON	50MM(5X) & 150MM(10X) f/5.6 SCHNEIDER -K. & 90MM (20X)f/4.5 WOLLENSAK	AS REQUIRED	5" f/4.5 ELGEET	12"F.L. FOR 3X 8.25"F.L. FOR 6X
L- FILM DRIVE & FOOTAGE COUNTER	MANUAL NONE	MOTORIZED FILM DRIVES IN X & Y, NONE	AS REQUIRED NONE SPECIFIED	MANUAL NONE	MOTORIZED & GANGED, 4 DIGIT COUNTER TO .1 FT.
M-REPRODUCTION	8" X 10" VACUUM FILM HOLDER	POLAROID ATTACHMENT ON SPEED-GRAPHIC CAMERA	NONE SPECIFIED	POLOROID CAMERA WITH PLEXI-GLASS LENSCREEN	9 1/2" WIDE ROLL AND CUT FILM HOLDERS, also 8 x 10
N-POWER REQUIRED	50AMP - 105 TO 125 VAC	55AMPS-115VAC	115 VAC, 60HZ- NO MAX. CURRENT SPECIFIED	15AMPS - 115VAC	6000WATTS, 115VAC, MAX.
O- SIZE & WEIGHT	58.75"H. X 51"D. X 27"W.	78"H. X 42" W. X 48"D. APPROX. 900 LBS	AS REQUIRED	59"H. X 30" D. X 42"W APPROX. 300 LBS	4'W X 4'H X 7'D 1500 LBS MAX.
P- SPECIAL FEATURES	PHOTOMETERS FOR BALANCED COLOR PRINTING, REMOTELY LOCATED BLOWER, FOLDED OPTICS WITH 2 MIRRORS, 1000 CFM COOLING.	BOTH ILLUMINATED SCREENS CAN BE USED A LIGHT TABLE, A SEPARATE STEREO BRIDGE IS PLACED OVER BOTH SCREENS		DESATURATION CAPABILITY, RAPID AND ACCURATE REGISTRATION WITH 4 IMAGES SIMULTANEOUSLY RECORDED ON SAME FILM. FALSE COLOR PRESENTATIONS	MODULARITY FOR FUTURE GROWTH

TABLE 3-1

ADDITIVE COLOR VIEWERS

sign criteria essential for defining the optimum PMV since that is the function of the specification. Since the amount of "available" apparatus and techniques involving additive color viewing is limited, Table 3-1 included the USAETL Multiband Additive Color Viewer specification since this represents a piece of equipment presently under development by Philco-Ford.

As shown in Table 3-1, the following Viewer Parameters were selected:

A- Magnification-factors or range provided primarily by projection of the spectral images with additional magnification of the superimposed image by magnifier or microscope.

B- Number of Channels, Film Size and Capacity- number of spectral images to be precisely registered and superimposed; the width and length of roll film formats accommodated.

C- Film Gate (Format)- size of projection gate to specify coverage for optics

D- Film Flattening- specifies function for evolving detail design criteria.

E- Screen Size and Material- dimensions presented to operator/analyst re human engineering display criteria and interface with screen brightness, magnification and format specifications.

F- Resolution- defines expected quality of system output either at the screen or what input (short conjugate) capability is outputted.

G- Registration- associated with resolution in relating to the quality of the superimposed image by virtue of the magnitude of image displacement from theoretically perfect position.

H- Illumination and Dimming Control- relates to screen brightness, uniformity and its control.

I- Filters- spectral bandwidths.

J- Image Positioning- precision mechanism provided to facilitate registration.

K- Projection Lenses- defines focal length and aperture as related to interfacing with other sub-systems and relative effect on resolution, brightness, availability, size, weight, etc.

L- Film Drive and Footage Counter- indicates expected function and usage of viewer relative to its ease of operation and productivity in transporting film.

M- Reproduction- type and capability

N- Power Required- type and amount of power needed.

O- Size and Weight- defines physical parameters.

P- Special Features- lists those additional important functional features considered significant.

3.3. Evaluation of Data

The tabulation of data in Table 3-1, for the various parameters enumerated above, would provide the capability for a rapid and concise parameteric comparison, relative to the state-of-the-art, if there was more available equipment in the "present" state-of-the-art, Tables 3-2 through 3-5 illustrate how effective this type of comparison can be when sufficient data is available, as in the case of standard rear projection viewers having multiple magnifications. Another pertinent factor to

MANUFACTURER	19-RICHARDSON	20-NRI	21-NRI	22-NORTRONICS	23-HOUSTON-FEARLESS	24-B & L	OPTIMUM REQUIREMENTS
NAME	MODEL 706F	VARISCAN	VARISCAN, MARK II	REAR PROJECTION VIEWER MODEL 707R	MODEL MPS-3	SLOPING SCREEN VIEWER	
A - MAGNIFICATION	5X, 11X AND 20X, FIXED	3X, 6X, 12X AND 30X, FIXED	3X, 6X, 12X AND 30X FIXED 48X MAGNIFICATION OPTIONAL	6X, 12X and 30X, FIXED	7.5X, 10X, 15X OR 30X, FIXED	5X, 10X, 15X AND 25X, FIXED	PRIMARY FIXED STEP - 4X, 10X, 40X
B - SCREEN SIZE	28 X 28	30 X 30	30 X 30 INCHES	30 X 30 INCHES	24 X 24 INCHES	30 X 30 INCHES	PRIMARY - 20 X 20 INCHES
C - RESOLUTION	40 L/MM AT 5X 90 L/MM AT 15X 150 L/MM AT 30X } ON AXIS	5 L/MM AT SCREEN	180-200 L/MM AT 30X		6 L/MM PER POWER AT SCREEN		150 L/MM AT 4X AND 10X 400 L/MM AT 40X
D - ILLUMINATION	30 FT. - LAMBERTS AT 30X ON AXIS W. 1.0 N.D. FILTER IN GATE, 20% FALL-OFF AT CORNERS	200 FT. - LAMBERTS AT MAGNIFICATION WITH NO FILM IN GATE 30% FALL-OFF AT CORNERS	1000 WATT LAMP. VARIABLE DIMMING CONTROL		25 FOOT CANDLES AT SCREEN	VARIABLE BRIGHTNESS CONTROL KNOB	PRIMARY - 1500-WATT QUARTZ IODINE LAMP, 50 FT. LAMBERTS AT SCREEN AT ALL MAGNIFICATIONS
E - FOCUS	FINE FOCUS CONTROL	FINE FOCUS CONTROL	VARIABLE FOCUS CONTROL				FINE FOCUSING CONTROL MUST BE INCLUDED.
F - FILM GATE	5 X 5 INCHES	10 X 10 INCHES	9 X 9 INCHES		2.75 X 2.75; VACUUM FILM HOLDDOWN	9 X 9 INCHES	PRIMARY - 5 X 5 INCHES
G - IMAGE ROTATION	360°, ENTIRE FILM TRANSPORT	± 180° ENTIRE FILM TRANSPORT	± 180°; PLATFORM ROTATION	360°		340°	360°, FOR PRIMARY AND AUXILIARY VIEWERS
H - FILM SIZES	35 OR 70 MM X 1000 FT., 5 OR 9-1/2" X 500 FT.	35 OR 70 MM X 1000 FT. 5 OR 9-1/2" X 500 FT.	35 MM to 9-1/2 INCHES X 1000 FT.	UP TO 9-1/2 INCHES WIDE	70 MM	35 MM TO 9-1/2 INCHES X 1000 FT.	ROLL FILM - 35 MM TO 9 1/2 INCH WIDTHS X 1000 FT.
I - SLEW SPEED	100 FPM	50 TO 250 FPM	0.01 IN./SEC. TO 250 FPM		.25 IN/SEC TO 60 IN/SEC	FORWARD OR REVERSE AT SPEEDS RANGING FROM 0.5 FPM to 120 FPM	MOTORIZED WITH MANUAL OVERRIDE AND OPERATION, UP TO 250 FPM
J - SCAN SPEED	1/2 TO 25 FPM (.1 TO 5 IN./SEC.)	1/2 TO 25 FPM (.1 TO 3 IN./SEC.)	.005 IN./SEC TO 4 IN/SEC.				0.1 IN/SEC TO 5.0 IN/SEC. NO NOTICEABLE JITTER.
K - LATERAL DRIVE	± 4-1/2 INCHES	ANY AREA OF 9-1/2 INCH FILM	ANY AREA OF 9-1/2 INCH FILM			ANY AREA OF 9-1/2" FILM CAN BE VIEWED REGARDLESS OF MAGNIFICATION	PRIMARY: ±5" IN Y DIRECTION AUXILIARY: ±1.9" IN X ±1.4" IN Y
L - CONTROL	JOYSTICK	JOYSTICK	JOYSTICK		JOYSTICK	KNOBS AND SWITCHES	JOY STICK AND KNOBS
M - FOOTAGE COUNTER	3 DIGIT, RESETTABLE	5 DIGIT, RESETTABLE	RESETTABLE			RESETTABLE	RESOLUTION - 0.1 FT., ACCURACY - 0.5 FT. OVER 1000 FT. ROLL, 250 FPM COUNT SPEED. AUXILIARY - CHIP RECORD INDICATOR
N - MENSURATION	± 2 MM	—	—	SHAFT ENCODERS. ON-LINE CAPABILITY.	± 1 MICRON OVER FULL 70 MM FRAME. DATATEX ROTARY ENCODERS	—	HIGH ACCURACY - 2 MICRONS OVER 9 X 9 INCH AREA. LOW ACCURACY - 0.02 MM OVER 10 INCHES. CAPABILITY FOR COORDINATE READOUT AND COMPUTER INPUT.
O - QUICK COPY PRINTING	—	—	—	—	—	—	PROJECTION PRINTING VARIABLE RANGE AS MAGNIFIED 4 X 5 INCH OR 8 1/2 X 11 INCH PRINTS. EXPOSURE TIME VARIABLE UP TO 60 SECONDS.
P - DIMENSIONS	62W X 70H X 36D	35W X 77H X 87D	68H X 90L X 51W		53W X 64H X 54D	41W X 75-1/2H X 65D	TO BE A MINIMUM
Q - WEIGHT	1500 LBS.	1800 LBS.			1300 LBS.	700 LBS.	TO BE A MINIMUM
R - POWER	—	—			110 V, 60 CYCLES	115 V, 50 CPS	115V, 60 HERTZ, SINGLE PHASE
S - SPECIAL FEATURES	GEOMETRIC DISTORTION < 0.1% OVER ENTIRE SCREEN.	LINEAR DISTORTION < 1% OVER ENTIRE SCREEN. "HORNING" CAPABILITY IN LATERAL ROTATIONAL DRIVES			THREE PROJECTION AND LIGHT SOURCES, SUPERPOSITIONING OF IMAGES IN THREE VIEWING SYSTEMS.	IMAGE IS FORMED ON TRANSLUCENT DRAFTING MATERIAL POSITIONED FLAT ON GLASS SURFACE. ANNOTATIONS CAN THEN BE MADE ON TRANSLUCENT OVERLAY SURFACE.	- PROVISION FOR DIRECT VIEWING AND ANNOTATING OF FILM IN TRANSPORT. - COMPLETE PROVISION FOR SELF-CONTAINED PHOTOGRAPHIC DEVELOPMENT PROCESSES.

MANUFACTURER	25-FMA	26-IBM	27-ITEK	28-ITEK	29-KODAK	30-GPL	OPTIMUM REQUIREMENTS
NAME	RAPID SCREENING VIEWER	MICRO VIEWER MODEL 9949	PI-4 CONSOLE	FC-1 FILM CHIP VIEWER	VIEWER, AR-56A	VIEWING CONSOLE	
A - MAGNIFICATION	5X, 15X AND 30X FIXED	6.5X AND 15X FIXED	5X AND 10X, FIXED	4.3X AND 17.4X	25X AND 60X, FIXED	9X, 12X, 15X AND 25X, FIXED	PRIMARY FIXED STEP - 4X, 10X, 42X
B - SCREEN SIZE	30 X 30 INCHES	8 X 10 INCH NON-GLARE SCREEN	16 X 22 INCHES	15 X 21 INCHES		22 X 25 INCHES	PRIMARY - 30 X 30 INCHES
C - RESOLUTION	GREATER 100 L/MM AT 30X		50 L/MM AT 5X 90 L/MM AT 10X	40 L/MM AT 4X 150 L/MM at 17.4X		6 L/MM AWAR AT ALL MAGNIFICATIONS	150 L/MM AT 4X AND 10X 400 L/MM AT 42X
D - ILLUMINATION	1000 FOOT LAMBERTS AT VIEWING SCREEN					VARIABLE FROM 40 TO 400 FOOT LAMBERTS. 900 WATT XENON ARC LAMP.	PRIMARY - 1500 - WATT QUARTZ IODINE LAMP. 30 FT. LAMBERTS AT SCREEN AT ALL MAGNIFICATIONS
E - FOCUS		FINE FOCUS BARREL	FINE FOCUS CONTROL	FINE FOCUS CONTROL	FINE FOCUS CONTROL	FINE FOCUS CONTROL	FINE FOCUSING CONTROL MUST BE INCLUDED.
F - FILM GATE				2.75 X 4.86 INCHES			PRIMARY - 5 X 5 INCHES AUXILIARY - 64 MM X 87 MM
G - IMAGE ROTATION	360°	—	360°		—		360° FOR PRIMARY AND AUXILIARY VIEWERS
H - FILM SIZES	STANDARD BASE AND THIN BASE FILMS RANGING FROM 70 MM TO 9-1/2 INCHES	ROLL FILM, APERTURE CARDS OR FILM CHIPS	70 MM FILM WIDTHS	70 MM X 5 INCHES	16 MM X 32 MM MINICARD FILM RECORDS	16 MM, 35 MM AND 70 MM MOTION PICTURE PHOTOGRAPHY.	ROLL FILM - 35 MM TO 9 1/2 INCH WIDTHS X 1000 FT.
I - SLEW SPEED		—			—	DIRECTIONAL, FLICKER-LESS RATES FROM 1 FRAME/SEC TO 64 FRAMES/SEC.	MOTORIZED WITH MANUAL OVERRIDE AND OPERATION. UP TO 250 FPM
J - SCAN SPEED		—			—		0.1 IN/SEC TO 5.0 IN/SEC NO NOTICEABLE JITTER
K - LATERAL DRIVE		—			MANUAL IMAGE POSITIONING	X - Y MOTION STAGE TO VIEW ANY POR-TION OF IMAGE	PRIMARY: ± 5" Y DIRECTION AUXILIARY: - ± 1.9" IN X ± 1.4" IN Y
L - CONTROLS		JOYSTICK				JOYSTICK	JOY STICK AND KNOBS
M - FOOTAGE COUNTER		—			—		RESOLUTION: - 0.1 FT., ACCURACY: 0.5 FT. OVER 1000 FT. ROLL 250 FPM COUNT SPEED. AUXILIARY - CHIP RECORD INDICATOR
N - MENSURATION	ELECTRICAL OUTPUT WITH ACCURACY OF 0.010 INCHES AT ALL MAGNIFICATIONS	—	ON LINE CAPABILITY	—	—	—	HIGH ACCURACY - 2 MICRONS OVER 5 X 5 INCH AREA. LOW ACCURACY - 0.02 MM OVER 10 INCHES. CAPABILITY FOR COORDINATE READOUT AND COMPUTER INPUT.
O - QUICK COPY PRINTING	CAN PRODUCE PHOTO ENLARGEMENT OF ANY IMAGE AS VIEWED ON SCREEN	—	—	—	—	DIFFERENTIAL DENSI-TOMETRIC MEASURING AND RECORDING FACILITY.	PROJECTION PRINTING VARIABLE RANGE AS MAGNIFIED 4 X 5 INCH OR 8 1/2 X 11 INCH PRINTS. EXPOSURE TIME VARIABLE UP TO 60 SECONDS.
P - DIMENSIONS		7 X 14 X 11	84 X 45 X 46	36 X 24 X 22	19H X 21W X 25L	56W X 78D X 61H	TO BE A MINIMUM
Q - WEIGHT		15 LBS.			110 LBS.	1200 LBS.	TO BE A MINIMUM
R - POWER		110 V, 60 CPS	1950 LBS.	115 V, AC 1/2 KW	105 TO 125 VAC, 60 CPS	115 V, 60 CY.	115V, 60 HERTZ, SINGLE PHASE
S - SPECIAL FEATURES	COMPLETE WITH PROVISIONS FOR SELF-CONTAINED PHOTOGRAPHIC DEVELOP-MENT. PROVISION FOR DIRECT VIEWING OF FILM IN TRANSPORT WITH REAR ILLUMINATION SOURCE (AS LIGHT TABLE).	SMALL, COMPACT DESK SIZE VIEWER FOR USE UNDER NORMAL LIGHT CONDITIONS.	DUAL PROJECTION SYS-TEM FOR SIDE BY SIDE COMPARISON VIEWING AND SUPERIMPOSITION			FULLY COLOR CORRECT-ED OPTICAL SYSTEM WITH-IN 4000 TO 7000 ANGSTROM RANGE. PAPER TAPE READ-ER AND PUNCHED CARD READOUT (OPTIONAL)	- PROVISION FOR DIRECT VIEWING AND ANNOTATING OF FILM IN TRANSPORT. - COMPLETE PROVISION FOR SELF-CONTAINED PHOTOGRAPHIC DEVELOPMENT PROCESS.

TABLE 3-5 REAR PROJECTION VIEWERS PARAMETERS - MULTIPLE FIXED MAGNIFICATIONS

MANUFACTURER	31-NORTRONICS	32-B & L	33-B & L	34-B & L	35-ITEK	36-DEV. OBJECTIVES	OPTIMUM REQUIREMENTS
NAME	COMPARISON VIEWER	PRIMARY CHANNEL VIEWER (MSSV)	AUXILIARY CHANNEL VIEWER (MSSV)	VARIABLE MAGNIFICATION PROJECTOR	S-2 SCREENING VIEWER	R.P.V.	
A - MAGNIFICATION	1.5X TO 20X, CONTINUOUSLY VARIABLE	3X TO 30X, CONTINUOUSLY VARIABLE IN 3 STEPS, 3X TO 9X, 9X TO 18X, 15X TO 30X.	3X TO 18X, CONTINUOUSLY VARIABLE	2.5X TO 15X CONTINUOUSLY VARIABLE	1.9X TO 10X CONTINUOUSLY VARIABLE	3X TO 70X IN 2 CONTINUOUS PAR FOCUSED RANGES	PRIMARY CONT. VAR. 4X TO 48X 12:1 RANGE AUXILIARY CONT. VAR. 4:1 RANGE, 2X TO 8X.
B - SCREEN SIZE	15 X 15 INCHES	20 X 20 INCHES	20 X 20 INCHES	24 X 24 INCHES HORIZONTAL		30 X 30	PRIMARY - 20 X 20 INCHES AUXILIARY - 17 W X 15 INCHES LONG
C - RESOLUTION	6 L/MM AT SCREEN 5 L/MM ON CORNERS	5 L/MM AWAR AT ALL MAGNIFICATIONS	6L/MM AWAR AT ALL MAGNIFICATIONS		3L/MM AWAR ON SCREEN	10 L/MM PER POWER ON ANY POINT ON THE SCREEN	.9 L/MM [illegible] FOR PRIMARY CONTINUOUSLY VARIABLE MAG. 10 L/MM PER POWER FOR AUXILIARY.
D - ILLUMINATION	1000 WATTS 600 FT. LAMBERTS WITH OPEN GATE DIMMING CONTROL	VARIABLE FROM 40 TO 400 FT. LAMBERTS. MAX. VARIATION ACROSS SCREEN - 20%	VARIABLE FROM 40 TO 400 FT. LAMBERTS. 20% MAXIMUM VARIATION	420-WATT QUARTZ IODINE LAMP		20 FT. LAMBERTS ON SCREEN WITH FILM OF 1.5 N.D. FILLING THE FILM PLANE. 10% MAX. DEVIATION. CONTINUOUSLY VARIABLE 100 TO 50%	PRIMARY - 1500-WATT QUARTZ IODINE LAMP, 30 FT. LAMBERTS AT SCREEN AT ALL MAGNIFICATIONS AUXILIARY - 450-WATT QUARTZ IODINE LAMP, 30 FT. LAMBERTS BRIGHTNESS.
E - FOCUS	FINE FOCUS CONTROL	COURSE AND FINE CONTROL	COARSE AND FINE CONTROL		FINE FOCUS CONTROL	AUTO FOCUS	FINE FOCUSING CONTROL MUST BE INCLUDED.
F - FILM GATE	4-1/2 X 4-1/2 INCHES	5 X 5 INCHES	5 X 5 INCHES	4 X 4 INCHES GLASS PLATENS FOR FILM FLATNESS		9-1/2 X 9-1/2 INCHES	PRIMARY - 5 X 5 INCHES. AUXILIARY - 64 MM X 87 MM
G - IMAGE ROTATION	360°; PRISM	360°	—			360°	360°, FOR PRIMARY AND AUXILIARY VIEWERS.
H - FILM SIZES	70MM AND 5 INCHES X 1000 FT.	70MM TO 9-1/2 INCHES X 1000 FT.	70MM TO 5 INCHES X 1000 FT.	70MM TO 9-1/2 INCHES X 200 FT.	70MM TO 9-1/2 INCHES X 500 FT.	70 MM TO 9-1/2" X 1000 FT. ADJUSTABLE DARK SLIDE FOR NARROW WIDTH FILM	ROLL FILM - 35 MM TO 9 1/2 INCH WIDTHS X 1500 FT. FILM CHIPS - UP TO 100 (70 X 100 MM FILM CHIPS
I - SLEW SPEED		.09 IN/SEC TO 30 IN/SEC	.09 IN/SEC TO 30 IN/SEC	MANUAL		HIGH SPEED RAPID ADVANCE & REWIND	MOTORIZED WITH MANUAL OVERRIDE AND OPERATION. UP TO 250 FPM
J - SCAN SPEED		TO .12 IN/SEC	TO .12 IN/SEC		1/2 FPM TO 15 FPM	1000 TO 1 RANGE, SMOOTHLY VARIABLE FROM JUST BARELY MOVING	0.1 IN/SEC TO 5.0 IN/SEC. NO NOTICEABLE JITTER.
K - LATERAL DRIVE	ANY AREA OF FILM TO CENTER	± 4-1/2 INCHES	± 2-1/4 INCHES	MOVING FILM MANUALLY TO DESIRED POSITION ON SCREEN		TO POSITION ANY PORTION OF THE IMAGE TO CENTER	PRIMARY ± .5" IN Y DIRECTION AUXILIARY ± 1.9" IN X ± 1.4" IN Y
L - CONTROLS	JOYSTICK	JOYSTICK	JOYSTICK			JOYSTICK	JOY STICK AND KNOBS
M - FOOTAGE COUNTER	± 1 FT; RESETTABLE	RESETTABLE TO 1 FT IN 1000 FT	RESETTABLE TO 1 FT. IN 1000 FT.	—		RESETTABLE	RESOLUTION - 0.1 FT., ACCURACY - 0.5 FT OVER 1000 FT ROLL, 250 FPM COUNT SPEED. AUXILIARY - CHIP RECORD INDICATOR
N - MENSURATION	—	.001 OVER 4.5 INCHES .01 OVER 30 INCHES	.001 OVER 4.5 INCHES .01 OVER 30 INCHES	—		—	HIGH ACCURACY - 3 MICRONS OVER 9 X 9 INCH AREA. LOW ACCURACY - 0.03 MM OVER 10 INCHES. CAPABILITY FOR COORDINATE, READOUT AND COMPUTER INPUT
O - QUICK COPY PRINTING	—	—	—	—	—	—	PROJECTION PRINTING VARIABLE RANGE AS MAGNIFIED 4 X 5 INCH OR 8 1/2 X 11 INCH PRINTS, EXPOSURE TIME - VARIABLE UP TO 60 SECONDS.
P - DIMENSIONS	42-1/2 W X 51-1/2 H X 55D	48W X 83-1/2H X 98L	48W X 83-1/2H X 94D	50W X 32D X 60H	84 X 45 X 56	34-1/2W X 80HX X-L	TO BE A MINIMUM
Q - WEIGHT	1000 LBS			540 LBS		—	TO BE A MINIMUM
R - POWER						—	115V, 60 HERTZ, SINGLE PHASE
S - SPECIAL FEATURES	-DUAL VIEWER (TWO SEPARATE SCREEN CONFIGURATIONS) -AUTOMATIC DIMMING CONTROL WHEN CHANGING MAGNIFICATION	-DIRECT STEREOVIEWING CAPABILITY -FILM CAN BE EDGE MARKED TO ACCURACY OF 0.1 INCHES FOR PURPOSES OF LOCATION.	-FILM CAN BE EDGE MARKED TO ACCURACY OF 0.1 INCHES.	-USED FOR TRANSFERRING INFORMATION FROM AERIAL PHOTOGRAPHS ONTO HORIZONTAL TRACING SURFACE.	-FIVE SELECTABLE MAGNIFICATIONS	MAX. FILM FLATNESS IN BOTH STATIC & DYNAMIC MODES. AUTOMATICALLY COMPENSATE FOR ANY FOCUS CHANGE WHEN FILM IS TRANSPORTED	- PROVISION FOR DIRECT VIEWING AND ANNOTATING OF FILM IN TRANSPORT. - COMPLETE PROVISION FOR SELF-CONTAINED PHOTOGRAPHIC DEVELOPMENT PROCESS.

TABLE 3-4 REAR PROJECTION VIEWERS PARAMETERS - CONTINUOUSLY VARIABLE MAGNIFICATION

MANUFACTURER	37-O[illegible]HANISMS	[illegible]	[illegible]	[illegible]-GPL	41-ITEK	42-ITEK	OPTIMUM REQUIREMENTS
NAME	ZOOM PROJECTION VIEWER	SCREENING VIEWER	RADAR IMAGE CORRELATION VIEWER	RADIC-1 TV SYSTEM	ELECTRONIC VIEWER MODEL 3570	ELECTRONIC VIEWER MODEL 3580	
A - MAGNIFICATION	1 TO 4X, CONTINUOUSLY VARIABLE	2X TO 6.5X, CONTINUOUSLY VARIABLE	2X TO 10X	10X TO 250X	CONTINUOUSLY VARIABLE, STEPLESS, IN-FOCUS MAGNIFICATIONS UP TO 500X	CONTINUOUSLY VARIABLE TO 220X (TOTAL RANGE)	PRIMARY CONT. VAR. 4X TO 45X 10:1 RANGE AUXILIARY CONT. VAR. - 4:1 RANGE, 2X TO 8X
B - SCREEN SIZE	9 X 18 INCHES	18 X 30 INCHES		14 INCH MONITOR	24 INCH MONITOR		PRIMARY - 20 X 20 INCHES AUXILIARY - 12 W X 16 INCHES LONG
C - RESOLUTION	20 L/MM AT 4X	10 TO 23 L/MM ON SCREEN	60 L/MM AT 10X	1000-LINE SYSTEM	IN EXCESS OF 50 L/MM AT MAGNIFICATION FACTORS GREATER THAN 150X		6 L/MM PER POWER FOR PRIMARY CONTINUOUSLY VARIABLE MAGNIFIED [illegible] L/MM FOR [illegible] AUXILIARY.
D - ILLUMINATION	OPERATOR ILLUMINATION CONTROL	1500 W. LAMP W. PLASTIC CONDENSER ELEMENTS SEALED IN NITROGEN.	CONTINUOUSLY VARIABLE FROM 5 TO 50 FT. LAMBERTS		FLYING-SPOT-SCANNER METHOD	SCANNER TYPE CRT	PRIMARY - 1500 - WATT QUARTZ IODINE LAMP, 30 FT. LAMBERTS AT SCREEN AT ALL MAGNIFICATIONS AUXILIARY - 1000 WATT QUARTZ IODINE LAMP, 20 FT. LAMBERTS BRIGHTNESS.
E - FOCUS	FINE FOCUS CONTROL	FINE FOCUS CONTROL					FINE FOCUSING CONTROL MUST BE INCLUDED.
F - FILM GATE	9 X 9 INCHES	10 X 20 INCHES					PRIMARY - 5 X 5 INCHES AUXILIARY - 64 MM X 67 MM
G - IMAGE ROTATION	OPTIONAL	—				360°	360°, FOR PRIMARY AND AUXILIARY VIEWERS
H - FILM SIZES	70MM TO 9 1/2 INCHES X 500 FT	70MM TO 9 1/2 INCHES X 500 FT	70MM, 5 INCHES OR 9 1/2 INCHES X 100 FT.	5000 FILM CHIPS AND APERTURE CARDS	35MM AND 70MM FILM (ROLL FILM, FILM CHIPS, APERTURE CARDS AND MICROFICHE)	16MM TO 5 INCHES X 100 FT.	ROLL FILM - 35 MM TO 9 1/2 IN. IN WIDTHS X 1000 FT FILM CHIPS - UP TO 150 70 X 150 MM FILM CHIPS
I - SLEW SPEED	20 FPM	100 FPM		—			MOTORIZED WITH MANUAL OVERRIDE AND OPERATION, UP TO 250 FPM
J - SCAN SPEED		0.2 TO 20 FPM		—			0.1 IN/SEC TO 5.0 IN/SEC NO NOTICEABLE JITTER
K - LATERAL DRIVE	ANY AREA OF IMAGE TO CENTER	7" OF TRAVEL		X-Y SCANNING	X-Y POSITIONING	TO 3 FEET/SEC.	PRIMARY: ± 5" IN Y DIRECTION AUXILIARY: ± 1.2" IN X ± 1.4" IN Y
L - CONTROLS		JOYSTICK			KNOBS	JOYSTICK	JOY STICK AND KNOBS
M - FOOTAGE COUNTER	RESETTABLE TO 0.1 FT. ACCURACY	FRAME COUNTING, 70MM TO 35" LONG FRAMES					RESOLUTION: - 0.1 FT., ACCURACY: - 0.5 FT. OVER 1000 FT. ROLL 250 FPM COUNT SPEED. AUXILIARY - CHIP RECORD INDICATOR
N - MENSURATION	CROSS HAIRS AND DIGITIZERS	± 1 MM		—	—	—	HIGH ACCURACY - 3 MICRONS OVER 5 X 9 INCH AREA. LOW ACCURACY - 0.02 MM OVER 10 INCHES, CAPABILITY FOR COORDINATE READOUT AND COMPUTER INPUT.
O - QUICK COPY PRINTING	—	—	—	—	—	—	PROJECTION PRINTING VARIABLE RANGE AS MAGNIFIED 4 X 5 INCH [illegible] 8 X 10 INCH PRINTS, EXPOSURE TIME VARIABLE UP TO 10 SECONDS.
P - DIMENSIONS		44WX92HX108L				46HX36WX48L	TO BE A MINIMUM
Q - WEIGHT		2400 LBS				300 LBS	TO BE A MINIMUM
R - POWER		5 KW			115V, 60 CY., 750 WATTS	600 WATTS	115V, 60 HERTZ, SINGLE PHASE
S - SPECIAL FEATURES		SERVO CONTROLLED AUTOFOCUS. FILM FLATTENING WHILE SCANNING. 10"/F11 ARTAR LENS	RADAR PROJECTOR	ELECTRONIC STORAGE, RETRIEVAL AND DISPLAY. AUTOMATIC CHIP EJECTION, INSERTION AND RETURN TO STORAGE.	IMAGE ENHANCEMENT INCLUDES INSTANT SWITCHING FROM POSITIVE TO NEGATIVE DISPLAY		- PROVISION FOR DIRECT VIEWING AND ANNOTATING OF FILM IN [illegible]. - COMPLETE PROVISION FOR SELF-CONTAINED PHOTOGRAPHIC DEVELOPMENT PROCESSES.

TABLE 3-5 REAR PROJECTION VIEWERS PARAMETERS - CONTINUOUSLY VARIABLE MAGNIFICATION

consider is the validity of the data, or absolute accuracy of the stated parameters, particularly with respect to those of resolution, registration, brightness, ease of operation, reliability, etc. For absolute evaluation, equipment test data should be provided however, this we realize becomes impractical. Therefore, we can draw upon relevant experience and expertise to apply appropriate weighting factors so that a realistic evaluation can be made.

3.3.1 Magnification and Film Format

As can be seen from the four existing viewers tabulated in Table 3-1, magnifications ranging from 2X to 20X (+ 3X auxiliary magnifier) have been specified for this primary parameter. The number of discrete magnification steps vary from one to three for the basic projected images. Inherent with magnification considerations is the film format or size of the input imagery and its scale. The input imagery format ranges from 1" X 1" to 4 1/2" X 4 1/2".

3.3.2 Resolution/Registration

The resolution/registration capabilities of the viewers are directly related to their optical coverage (all other things such as lens focal length, distortion, calibration, matching, alignment, etc., being considered equal) so that the smaller the imagery format utilized, the greater will be the output quality. The theoretically best performance would be obtained with extremely small formats and the largest focal lengths which can be practically realized. This most critical parameter, which represents the effectiveness of the entire apparatus and related techniques, can not be effectively treated since there was no objective and impartial testing criteria equally applied to all four viewers. This is the one viewer parameter which is most suspect and difficult to absolutely define. The validity of the data can be questioned by the variations with which resolution/registration can be defined and specified, such as "on-axis", "minimum" or "anywhere in the format", "AWAR", or "on-axis with __ per cent fall-off in corners". Another significant variable or not too well defined term, is the contrast of the input material or test target. This is most frequently related to as high, medium or low contrast and again, there is not standardized means for handling this decriptor of the resolution parameter. The most accurate method for defining the performance of the elements of a system is by relating to its modulation transfer function (MTF) but here the additional complexity in making these MTF determinations have limited its utilization. In the final analysis there is the additional criteria that resolution (no matter how specified) does not completely define the quality of continuous tone photography. There is the hard to define distinction of acutance which can be independant of resolution.

3.3.3 Evaluation Summary

When the overall considerations for the PMV are correlated with the objectives defined in the work statement it becomes apparent from the comparisons presented by Table 3-1 that a very useful and flexible Precision Multiband Viewer can be designed around off-the-shelf hardware and using techniques which are within the current state-of-the-art. It can also be readily seen that the parameters specified for the NASA

PMV will provide capabilities which are readily attainable, practical to realize and which represent an extension of the existing available apparatus and techniques.

APPENDIX 3 A

Precision Multiband Viewer (PMV) Related Documents

1. Color Experimentation and Evaluation Device

   (Additive Color Viewer-Printer)

   Technical Report AFAL-TR-65-77, May 1965

   Air Force Avionics Laboratory

   Research and Technology Division

   Air Force Systems Command

   Wright-Patterson Air Force Base, Ohio

   By Itek Corp. under USAF Contract No. AF33(615)-1037

2. Additive Color Viewer

   Handbook of Operation and Maintenance Instructions for Additive Color Viewer.

   Unclassified Report AF30(602)3224, 1 April 1964

   Prepared under the sponsorship of

   Rome Air Development Center, ARDC, USAF

   Griffiss Air Force Base, New York

   by Giannini Scientific Corp., Santa Ana, California

3. Multiband Additive Color Viewer

   USAETL RFQ-DAAK02-69-Q-3356

   Department of the Army

   U.S. Army Topographic Command, Corps of Engineers

   Engineer Topographic Laboratories

   Fort Belvoir, Virginia 22060

Contract No. DAAK02-70-C-0145

Contractor: Aeronutronic Division

Philco-Ford

4. <u>Multispectral Film Viewer</u>

Technical Report SERG-TR-04, 1 September 1968

Long Island University

Science Engineering Research Group

Contractor: Fairchild Space and Defense Systems

4. DISCUSSION OF PROJECTION LENS CRITERIA FOR PRECISION MULTIBAND VIEWER

4. 1. GENERAL

In determining the detail design criteria for a set of four projection lenses to be used in the Precision Multiband Viewer, the first things to be considered are the basic parameters as required for any optical projection system; namely, resolution, field of coverage, distortion and aperture. In addition, there are the additional requirements for matching of focal lengths and the differential distortion between each lens throughout the field of coverage.

Various types of imagery can be used as input to the Precision Multispectral Viewer, therefore, we can consider the desired resolution objective as being capable of handling the best photographic image detail typically being obtained with existing reconnaissance camera systems. Although high definition aerial films, such as the fine grained Ektachrome SO-243 type, have the capability of resolving up to 230 lines per millimeter at a 1.6 to 1 target contrast ratio (low contrast), the best photographic image detail which is practically obtainable is in the order of 130 lines per millimeter.

The field of coverage of projection lenses to attain this degree of resolution should be $\leq 30^\circ$ total angle, with half this range usually used in high resolution projection devices to minimize typical aberrations. Since one of the operational objectives involving false color presentations is to have the capability of using any filter with any lens, there can be no advantages accruing from optimizing the resolution capability by selecting and working within a narrow spectral bandwidth.

The distortion characteristics are inter-related with the resolution whenever relatively high resolution (greater than 100 lines per millimeter) is involved. To this is added the additional requirement of registration of superimposed imagery which, with respect to the distortion parameter, affects the differential distortions of each of the four lenses used in the Multispectral Precision Viewer. For purposes of insuring constant image detail, the projection lenses should have low radial distortion. Presently configured multiband projection viewers all have highlighted the significance of the aperture of the projection lenses. Since it is inherent in multiband projection systems that appropriate filters be applied to each projection channel, the loss of available energy is appreciable and therefore, the aperture of the projection lens should be as large as practically possible. Optimally, diffraction limited lenses having the largest apertures should be used but practical lens design problems and trade-offs of aberrations do not make this type of lens commercially available.

The criteria for exactly matching the focal lengths of the projection lenses is evident in the basic problem of registration. Techniques of utilizing large run, commercially available, off-the-shelf lenses and selecting lenses which best match and fit each other, can be used to minimize this basic problem.

This technique is even more significant for the criteria of differential distortion between lenses, particularly for the higher resolution imagery which is more readily degraded by poor registration.

4.2. MAGNIFICATION

The first criteria of the optical projection system relates to magnification which, as specified in the work statement, will be capable of magnifying the superimposed image in steps from one to twenty-five times over the original scale. One effective way to cover this magnification range is by the combination of discrete magnification steps of large area coverage supplemented with continuously variable magnification of small area coverage at the higher magnifications. This would be readily obtained by viewing a portion of the projected magnified aerial image with zoom optics having the capability of extending the discrete magnification by a factor of up to 4 to 1.

Considering a discrete magnification factor of 3 times applied to the input imagery, there are certain parameters which can now be analyzed. The first parameter affected is resolution in that the 130 lines per millimeter capability of the original imagery will now be 43 lines per millimeter on the screen. This is not a problem with present day projection screen materials which, although depending upon a diffuse coating to scatter the light and present the imagery on the screen plane, do have sufficient fineness of coating to present up to 70 lines per millimeter images. The 43 lines per millimeter resolution appearing on the projection screen is, of course, a degree of image detail which the unaided eye is not capable of resolving. With the average human eye considered to have a capability of about 8 lines per millimeter resolving power, there is still a factor of 5.45 times between what is considered available and what is being viewed. Application of a simple 6 times magnifier can then equate the two. Present day technological developments in integrated and micro-circuitry fabrication have led to the ready availability of wide angle,simple magnifiers covering a relatively large format with nominal distortion.

With high screen resolution, the projected aerial image, which would be 6 3/4 inches square for 70mm frames, can then be viewed with a standard low power, wide field, microscope having a zoom optical train of 4 to 1. With the appropriate eyepieces, this can extend the discrete 3 times projected magnification by another magnification range of say, 2 times through 8 times. Therefore, the interpreter/analyst will be viewing the image with a magnification system of 6 times through 24 times. With presently existing wide field microscopes, the coverage is approximately 7 inches divided by the magnification. This results in a viewing capability of about 3 1/2 inches diameter at the 6 times magnification reducing to a 7/8 inch diameter at the 24 times magnification, related to the aerial image, which is a 3 times magnification of the input format. If we were to consider a discrete magnification of 6 times for the projection viewer there would then be a 13 1/2 inch square format on the screen with an expected resolution of 21 lines per millimeter. Here again, application of a simple 3 times wide angle magnifier can readily bring the full resolution capability of the expected film imagery to the observer. Correspondingly, different eyepieces can be utilized in the zoom microscope to present an additional magnification range of 1 time through 4 times for again presenting a 6 times through 24 times viewing capability to the observer. By using this last specified microscope magnification range of 1 time through 4 times in conjunction with the discrete 3 times projection lens, a magnification range of 3 times

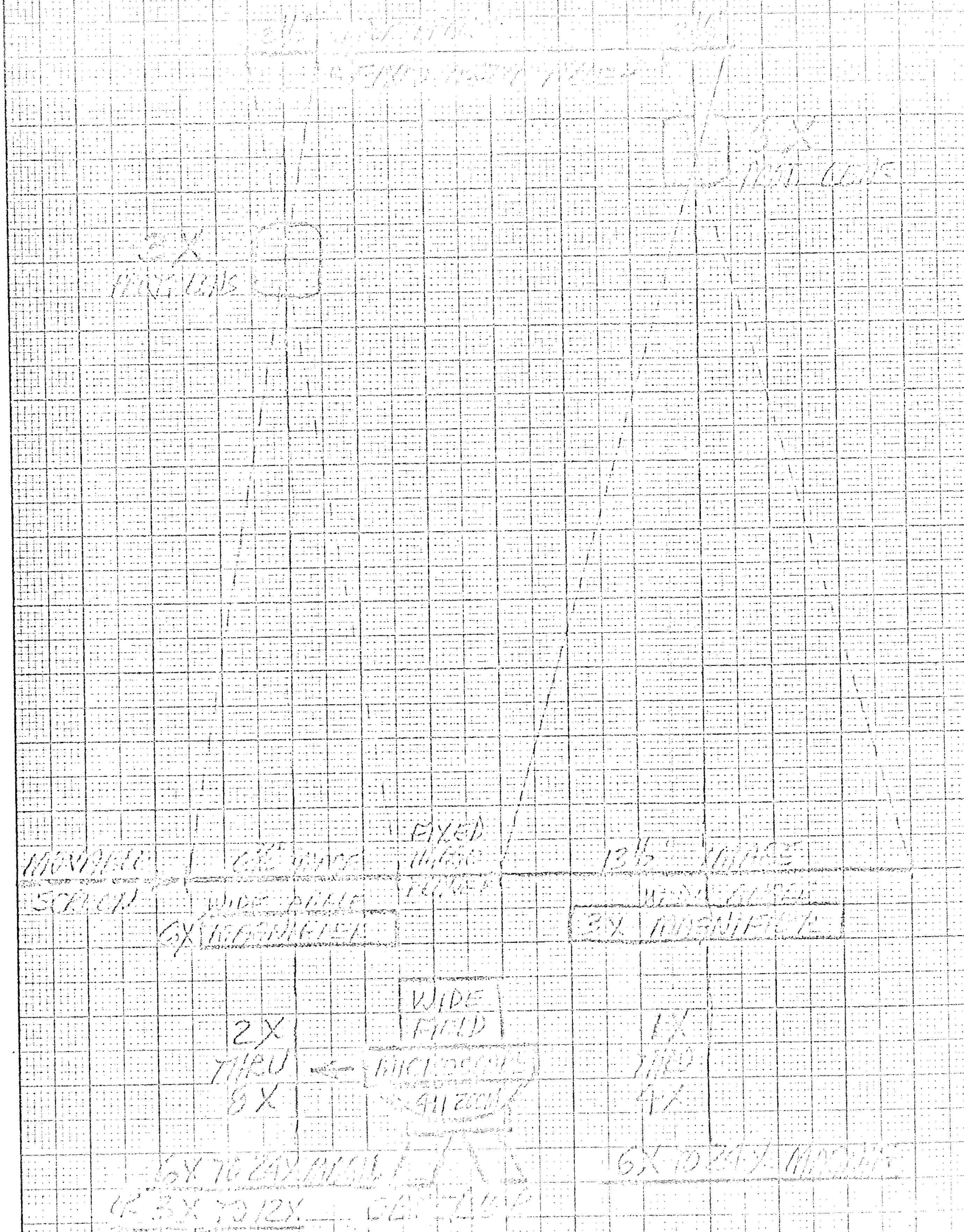


FIG. A1-

through 12 times is provided to the observer. The relationship of these magnification considerations is illustrated in Figure 4-1.

4.3 DISTORTION

Distortion criteria affects two basic parameters, resolution and registration in an inter-related fashion. The matching of the equivalent focal lengths, EFL, of each of the four lenses has a gross effect upon the registration of the four images. Hopefully, a good fit will be obtained, but the practical working Precision Multiband Viewer must provide precise adjustments for compensating and removing all residual errors. In correlation with EFL, consideration must be given to the absolute radial distortions of the lenses and the differential distortions from lens to lens. The absolute radial distortions will have a primary effect upon the resolution parameter whereas the absolute magnitudes, whatever they might be, would not affect the registration parameter as long as all four lenses had, identical magnitudes. Again, for practical applications even with extensive selecting and matching procedures, precise micrometric adjustments should be provided to correct for changes and variations. Figures 4.2 through 4.5 show some typical distortion calibration results for four off-the-shelf inexpensive commercial lenses. Table 4-1 presents distortion and resolution data for a specially designed commercially available lens which is made in much smaller quantities and is not as readily obtainable and costs approximately twice that of the preceding lens. Figure 4.6 shows the calibration for a high resolution lens used in a Photogrammetric Enlarger. All distortion values given are in mm for Figures 4.2 through 4.5 and are in microns for Figure 4.6.

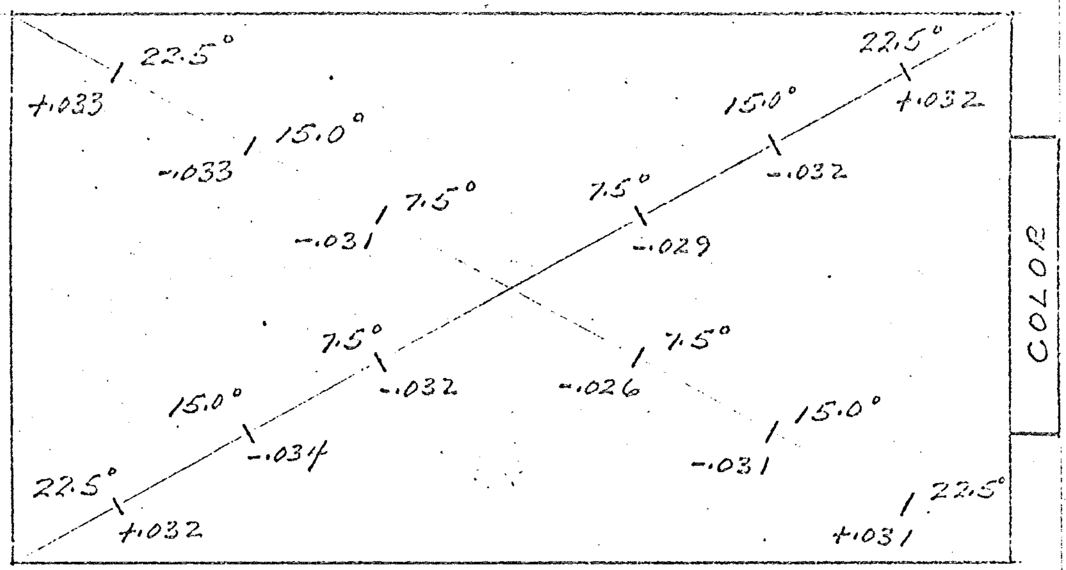
135 MM F/4.5 ELGEET LENS

SER. NO. 1 DATE 12-10-44

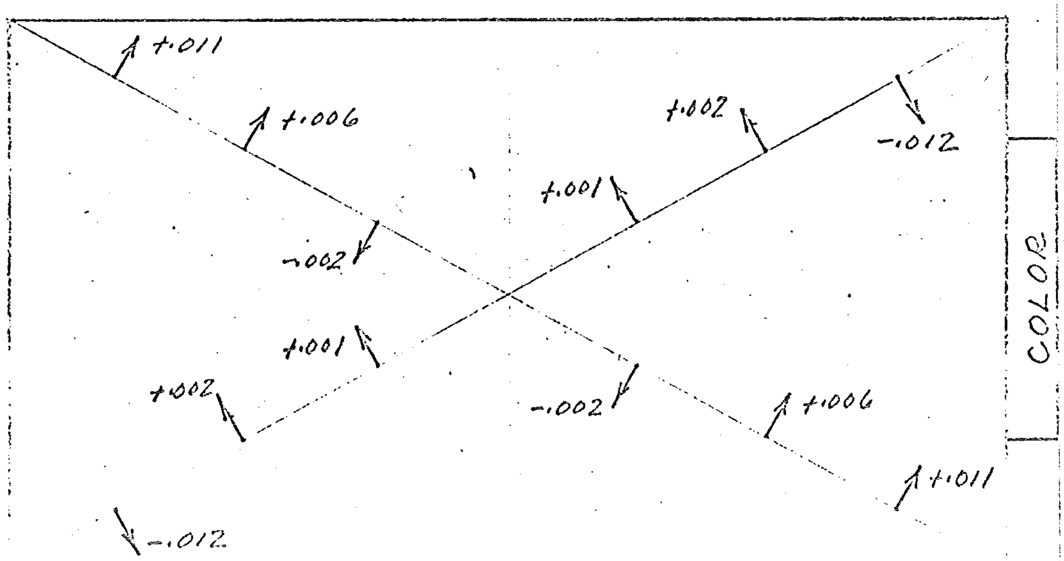
F.F.D. 4.808" **Figure 4-2** BY: Wm.B.

PLATES 0° & 90°

ASYMMETRIC RADIAL DISTORTION (mm)



TANGENTIAL DISTORTION



AVERAGE RADIAL DISTORTION (mm)

PLATE	7.5	15.0	22.5
0°	-.028	-.032	+.033

[illegible] [illegible]

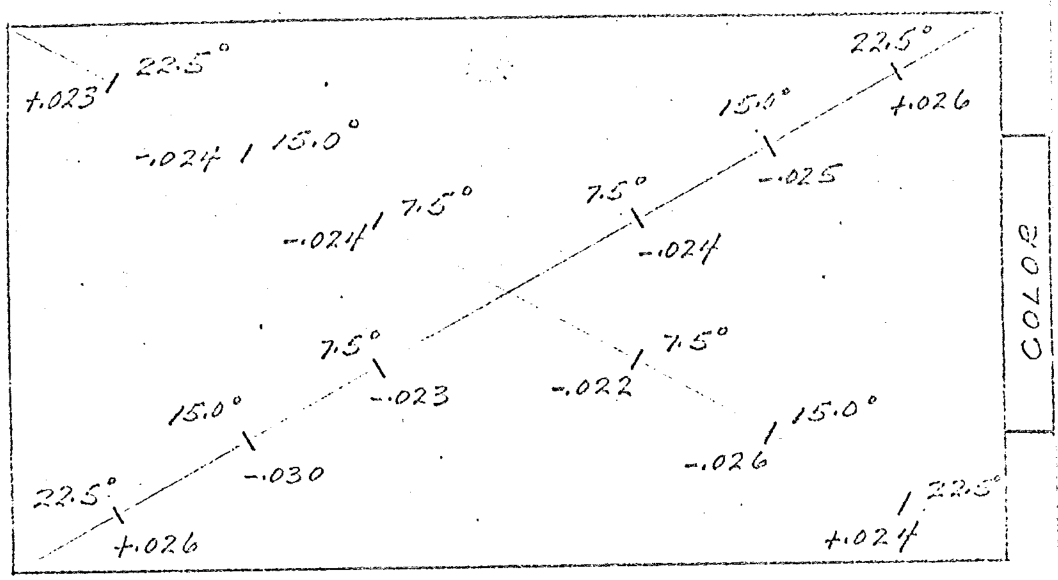
SER. NO. 2 DATE 12-10-[illegible]

F.F.D. 4737 BY: Wm. B.

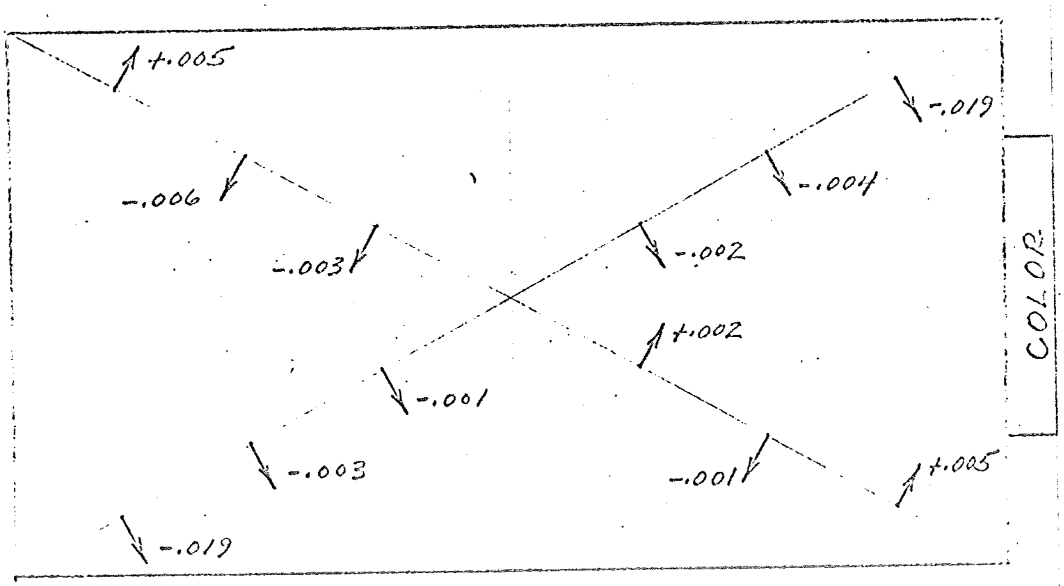
Figure 4-3

PLATES 0° & 90°

ASYMMETRIC RADIAL DISTORTION (mm)



TANGENTIAL DISTORTION



AVERAGE RADIAL DISTORTION (mm)

PLATE	7.5	15.0	22.5
0°	-.024	-.025	+.025
90°	-.024	-.027	+.026

135 mm F/4.5 ELGEET LENS

SER. NO. 3

DATE 12-10-[illegible]

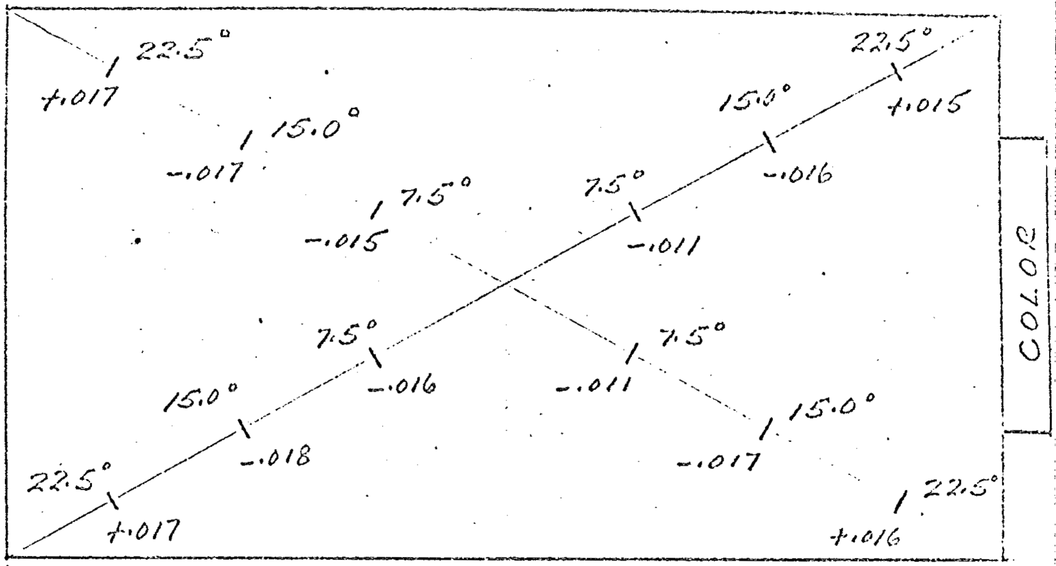
F.F.D. 4.804

Figure 4-4

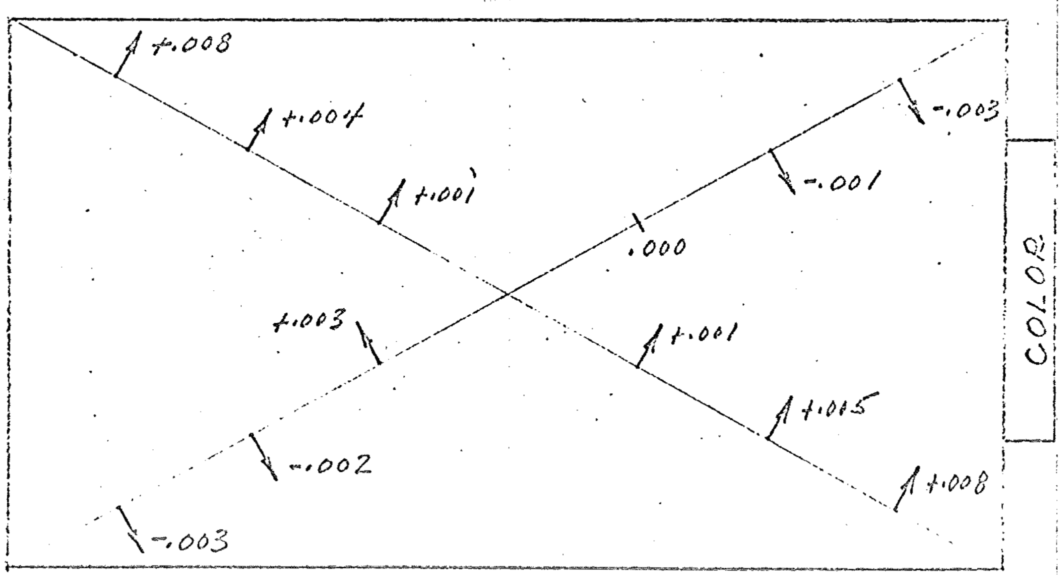
BY: Wm. R.

PLATES 0° & 90°

ASYMMETRIC RADIAL DISTORTION (mm)



TANGENTIAL DISTORTION



AVERAGE RADIAL DISTORTION (mm)

PLATE	7.5	15.0	22.5
0°	-.013	-.017	+.017

135 mm F/4.5 ELGEET LENS

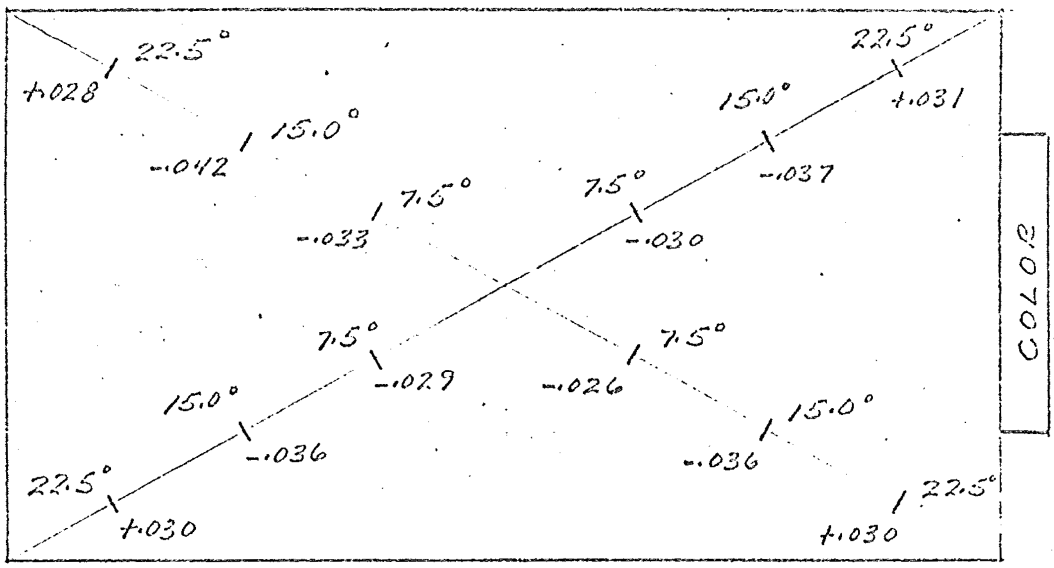
SER. NO. 4 DATE 12-16-[illegible]

F.F.D. 4.820 BY: Wm.B.

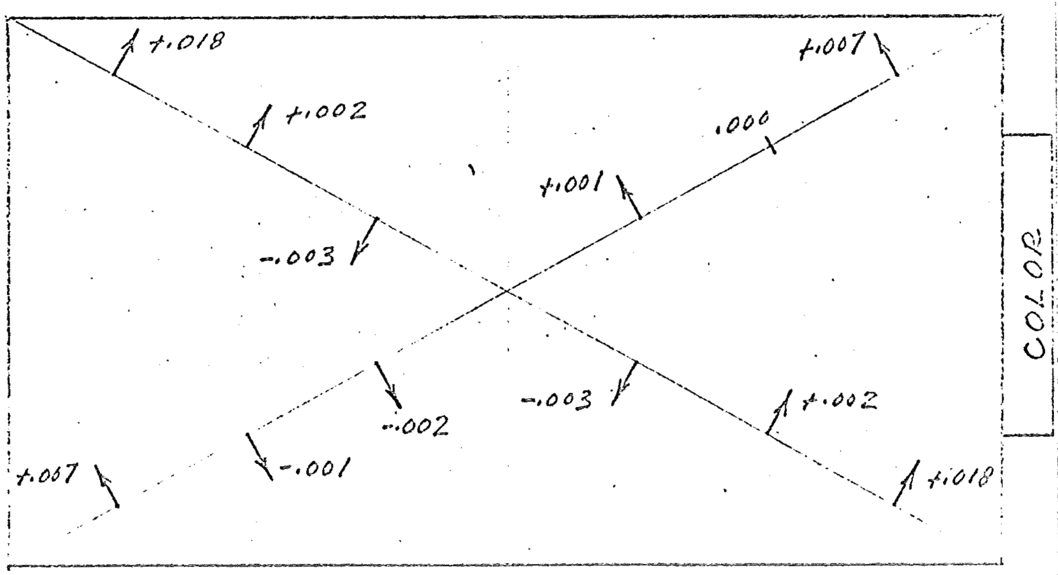
PLATES 0° & 90°

Figure 4-5

ASYMMETRIC RADIAL DISTORTION (mm)



TANGENTIAL DISTORTION



AVERAGE RADIAL DISTORTION (mm)

PLATE	7.5	15.0	22.5
0°	-.030	-.039	+.030
90°	-.030	-.036	+.031

KEUFFEL & ESSER CO.

O AXIS IS F-6 FOR 4.5" X 4.5" FORMAT

X - AXIS DISTORTION

	1	2	3	4	5	6	7	8	9	10	11
A	-4	-3	-2	-4	-4		+10	+9	+10	+8	+9
B	-2	-1	-1	-2	-3		+10	+9	+10	+5	+9
C	+1	+1	+1	-1	-1		+7	+4	+8	+9	+9
D	+1	+1	+1	-1	-2		+7	+4	+7	+4	+7
E	+1	+3	+3	+1	+1		+6	+2	+5	+3	+7
F						⊕					
G	+4	+4	+6	+3	+3		+1	-1	0	-2	+1
H	+4	+4	+5	+5	+5		-1	-3	-2	-4	-1
I	+4	+4	+4	+4	+4		-1	-5	-3	-6	-3
J	+3	+2	+6	+4	+4		-4	-5	-5	[illegible]	-6
K	+1	+2	+5	+4	+5		-4	-9	-8	-11	-8

Y - AXIS DISTORTION

	1	2	3	4	5	6	7	8	9	10	11
A	-15	-11	-9	-9	-9		-7	-7	-6	-12	-15
B	-10	-10	-10	-9	-9		-5	-5	-5	-5	-5
C	-7	-6	-6	-4	-3		-3	-1	-3	-3	-2
D	-7	-5	-5	-5	-3		-2	-2	-2	-2	-2
E	-4	-4	-4	-5	-3		-2	-3	-3	-1	-1
F						⊕					
G	+3	+3	+3	+3	+3		+6	+5	+4	+4	+3
H	+1	+2	+3	+5	+4		+4	+4	+4	+4	+4
I	+1	0	+1	+1	+5		+4	+3	+2	+3	+3
J	-2	0	+1	+3	+3		+5	[illegible]	[illegible]	[illegible]	[illegible]
K	-2	-1	+1	+2	+3		+5	+5	+5	+6	+3

FIGURE 46 - CALIBRATION OF 2X PHOTOGRAMMETRIC ENLARGER LENS

TABLE 4-1

DISTORTION AND RESOLUTION DATA FOR SPECIALLY DESIGNED COMMERCIAL LENS

RADIAL DISTORTION-RELATED TO EFL

5°	0 microns
10°	2 microns
15°	4 microns
20°	10 microns

RESOLUTION-LINES/MM

	RADIAL	TANGENTIAL
-20°	79	74
-15°	81	75
-10°	83	81
-5°	84	86
0°	84	84
+5°	83	81
+10°	82	78
+15°	81	75
+20°	79	66

4.4 RESOLUTION REQUIREMENT

Considering that the input film could have the resolution capability of the best photographic image detail practically obtainable, we have established 130 lines per millimeter as the requirement for this parameter. The resolution capability of an optical projection system is not determined by the projection lenses alone. There are other factors outside the projection optics which affect the resulting resolution. Some of these factors are:

- Illumination source
- Film flatness
- Perpendicularity of film plane to optical axis
- Flatness of mirrors used to fold optical path
- Alignment of mirrors used to fold optical path
- Flatness of projection screen
- Perpendicularity of projection screen to optical axis
- Spectral bandwidth of illumination
- Contrast ratio of input imagery
- Thermal effects upon the structure and air
- Stability of all structures
- Dirt, dust, smoke, fog or moisture, etc.

Another factor to be considered involves the way in which resolution is specified. For example, is the specified value referring to the resolution on-axis, AWAR(area-weighted average resoltion), or does it refer to the resolution required anywhere in the format? This last factor would then imply that the specified resolution is a minimum since in any real practical device, the on-axis resolution is better than that in the corners of the format, unless deliberately established that way. For most applications involving projection lenses where the practical restraints of coverage, size, weight, focal length, folding the optical path, etc., are traded-off, there is usually a broad enough coverage so that the resolution attained in the corners of the format is about half of that attained on-axis. This is not objectionable for the Precision Multiband Viewer, provided that the capability exists for positioning any desired point of interest on to the optical axis. If this capability is not provided, then the resolution requirement must account for the specified permissible falloff. Therefore, the resolution requirement of 130 lines per millimeter is considered to refer to the on-axis requirement and a falloff of resolution of 20 per cent in the corners, to 100 lines per millimeter, is acceptable. It is of course, realized that AWAR is commonly used but there is not significance in establishing this more tedious method of evaluating the resolution capability of the instrument. If greater falloff in resolution at the corners was permitted, the interrelated registration of the four images would be degraded.

4.5 SUMMARY OF PROJECTION LENS CRITERIA

The criteria affecting the projection lenses for the Precision Multiband Viewer are summarized as follows:

4.5.1 Discrete Magnifications: 3 times and 6 times for entire format

4.5.2. Zoom Magnifications: 3 times to 12 times and 6 times to 24 times with format of 7 inches divided by magnification

4.5.3. Resolution: 150 lines per millimeter on-axis with 20 per cent fall-off in corners.

5. PROJECTION SYSTEM DESIGN CRITERIA

5.1. Influence of Overall Configuration

The influence of the overall configuration upon the projection system design is basically one of the prime considerations underlying the usage of the PMV. In addition to the normal viewing tasks involving scanning, identification, interpretation, analysis, etc., the operator has to perform the exacting task of image registration. It is inherent in all design analyses to accent the functions which the operator performs so that for this type of system design human factors must be emphasized. Therefore, the displays, controls and all the many adjustments which the operator must effectively manipulate have to be optimally configured. Other usage factors which help define the overall configuration are:

- -environment in which PMV will be used
- -portability and movement considerations
- -size
- -weight
- -power consumption
- -cost

Making the appropriate trade-offs of all the variables involved in the system design requires complete understanding and knowledge of the objectives of the PMV. For example, highest optical performance is obtained on axis. Therefore, by employing extremely long focal length lenses we can effectively work on-axis for our required 2 1/4" format. However, the impracticality of designing a viewer configuration which is say 15 to 20 feet long, becomes apparent when the additional optical gain is evaluated against the corresponding increase in size, weight, cost, etc. Study and review of all types of optical projection viewers and similar types of operator oriented equipments indicates that the optimum configuration is the "viewing console" type. Many human factors and engineering studies have been made which define all the significant parameters and design details for this type of configuration. Eye level dimensions, location of displays and controls, operator reach, knee room, etc., have all been thoroughly studied and analyzed. Drawing RG-321-D1, of the Specification, is an example of a PMV which is configured in accordance with the preceding philosphy.

5.2. Projection Optics Focal Length

With a high performance optical system containing two sets of projection lenses (3X and 6X) it is inherent that the total path length (TPL) be exactly fixed and that only the lenses be moved when changing magnification. In order to do this with existing designed projection lenses it is best to modify the resulting magnification as long as we know exactly what it is. Consider usage of standard commercially available lenses of 8 1/4" (210mm) focal length for the 6X magnification and 12" focal length for the 3X magnification.

For the nominal 8 1/4" focal length (6X) lens we have:

$$\text{Object distance (O)} = \text{F.L.} + \text{F.L.}/M = 8.25 + 8.25/6 = 9.625''$$

$$\text{Image distance (I)} = \text{F.L.}(M+1) = 8.25(7) = 57.75''$$

$$\text{TPL} = 67.375''$$

For the nominal 12" focal length (3X) lens we have:

$O = 12 + 12/3 = 16''$

$I = 12(4) = 48''$

$TPL = 64''$

The difference of 3.375" in total path length is easily eliminated by shifting the magnification factor slightly. For example, as shown by the data of Table 5-1 plotted out in Figure 5.1, there are many exact magnification combinations which would have the same total path length (TPL) for the 12" F.L. (3X nominally) and the 8 1/4" F.L. (6X nominally) lenses.

It then becomes relatively simple to nominally select the discrete magnifications for these two lenses, having the same total path length. For example, the 8 1/4 " F.L. lens can be used at 5.7 X magnification in which case its TPL is 64.964". The corresponding magnification of the 12" F.L. lens, having the same TPL is 3.09X. Similarly, if the 8 1/4" F.L. lens is used at a magnification of 5.8X, the 12" F.L. lens is at 3.165X, for the same TPL. For further projection system design analysis, we will consider the usage of magnifications of 5.7X and 3.09X for the 8 1/4" and 12" F.L. lenses respectively.

As can be seen on Figure 5-1, the half angle coverage of the 12" F.L. lens is 5.6° and that of the 8 1/4" F.L. lens is 9.2° for the diagonal of the 2 1/4" format.

53. Discussion on Folding the Optical Path

When using long focal length lenses and the size and weight of the instrument become critical it becomes advantageous to insert mirrors

TABLE 5-1

12" F.L. Lens	I	O	T.P.L.
@ 3.0X Magnification	48	16	64
@ 3.1X Magnification	49.20	15.871	65.071
@ 3.14X Magnification	49.68	15.822	65.502
@ 3.15X Magnification	49.80	15.810	65.61
@ 3.2X Magnification	50.40	15.750	66.15

8 1/4" F.L. Lens	I	O	T.P.L.
@ 5.6X Magnification	54.450	9.723	64.173
@ 5.7X Magnification	55.275	9.698	64.964
@5.74X Magnification	55.605	9.687	65.295
@5.75X Magnification	55.688	9.685	65.372
@5.76X Magnification	55.770	9.682	65.452
@5.77X Magnification	55.853	9.680	65.532
@5.78X Magnification	55.915	9.677	65.592
@5.8 X Magnification	56.100	9.672	65.771
@5.9 X Magnification	56.925	9.648	66.575
@6.0 X Magnification	57.750	9.625	67.375

NOTE: Change in I is directly proportional to change in magnification

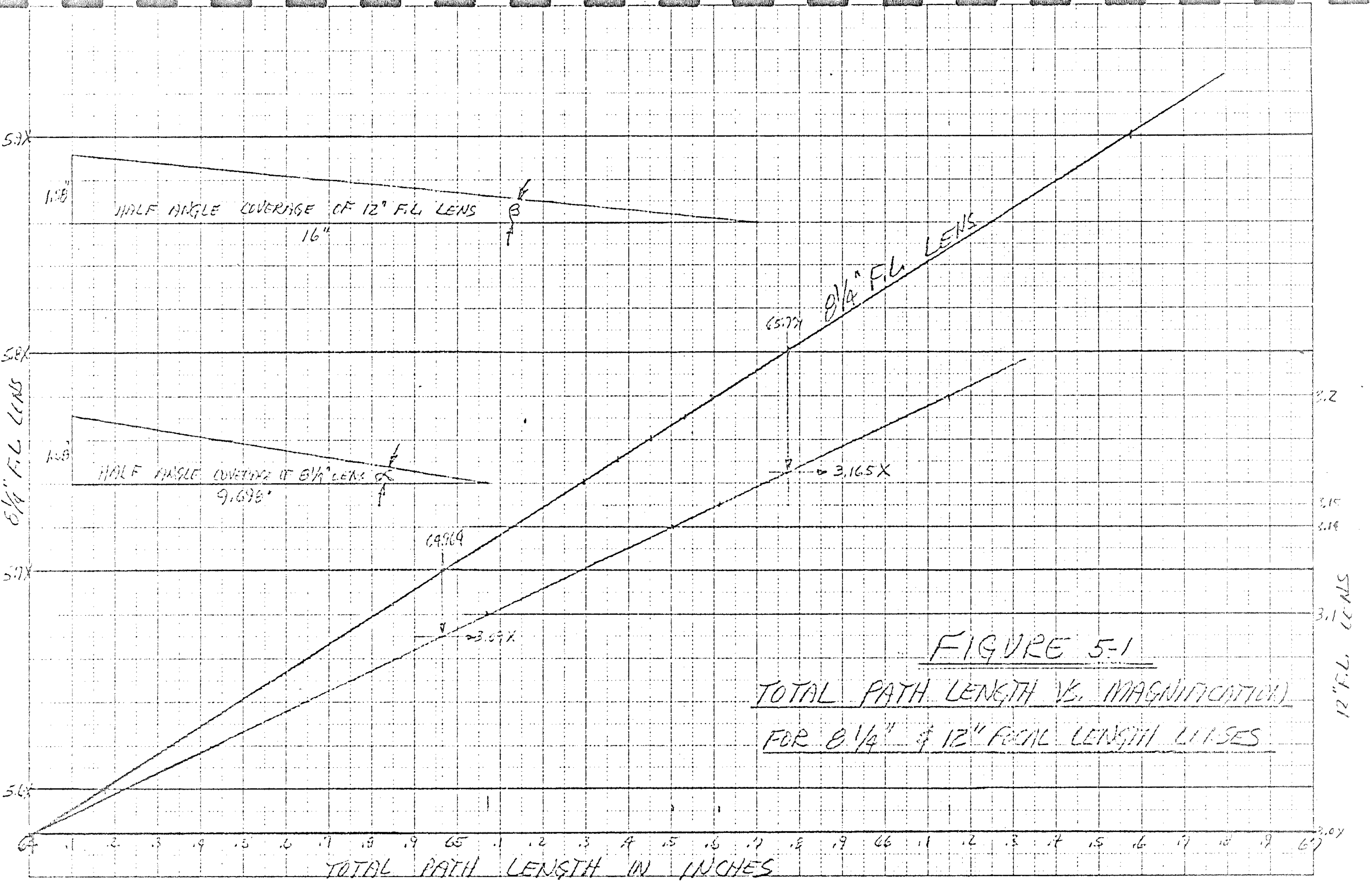


FIGURE 5-1
TOTAL PATH LENGTH VS. MAGNIFICATION
FOR 8¼" & 12" FOCAL LENGTH LENSES

in the optical path to reduce the size. Usage of a single mirror provides some additional complexity in alignment for focusing and for registration. Usage of multiple mirrors complicates the task even more so. Consider the normal flatness requirements of a mirror in a relatively high resolution single lens system. In this single image projection device the image projected off the mirror is influenced by the angle and the flatness of the reflective surface. Variations in angle result in keystoning types of image distortion, loss of geometric fidelity and loss of resolution in those portions of the projected image whose image distance has been shortened or lengthened. Variations in flatness affect the resolution primarily, by criteria such as astigmatism, and secondarily affect the positioning of the portions of the image. When the tradeoff analysis is conducted and the advantages and disadvantages of focal length/resolution/distortion/size/cost/weight/stability and all the other criteria involved are evaluated it becomes apparent that for the requirements defined in the work statement, the usage of longer focal length projection lenses are not required for the 100 l/mm and 70mm format requirements. Subsequently for the conjugate distances indicated in Table 5-1, the advantages of a mirror to fold the optics becomes questionable.

5.4 Illumination System Criteria

5.4.1 Condenser

The design of an effective illumination system for the PMV should be implemented with standard condenser lenses. The condenser lens should be positioned in the optical path in such a manner so as to image the filament of the projection light source to fill the aperture of the projection lens. When changing magnification there will be a significant variation in the position of the second projection lens. This can be accommodated by simultaneously inserting another condenser lens element into the condenser system to vary the throw of the filament's image, or by movement of the condenser lens itself, or by a combination of both. Because of the attenuation of projection lamp energy by the bandwidth filter, the PMV's illumination requirement for each optical axis are more severe than normal film rear projection system's. There will therefore be a higher amount of thermal energy generated by the light sources. In addition to cooling, normally by air flow, a specially coated mirror (dichroic) can be inserted between the lamp and the condenser lens to remove the radiant energy which would cause unnecessary heating at the film gate. This coating would transmit the radiant heat from the light source and only reflect the visible wavelengths of energy, as shown in Figure 5-2. Correspondingly, a heat absorbing glass can be inserted between the dichroic mirror and the light source which would block the thermal energy and only transmit the usable visible energy.

5.4.2 Light Source

The selection of the proper light source for the PMV is an important factor in obtaining sufficient contrast for the image analyst. There is a fairly wide selection of standard light sources available so that the primary objective, of designing the PMV around off-the-shelf hardware, can be readily attained with respect to this parameter. On the basis of various trade-offs between luminance, reliability, maintainability, cost,

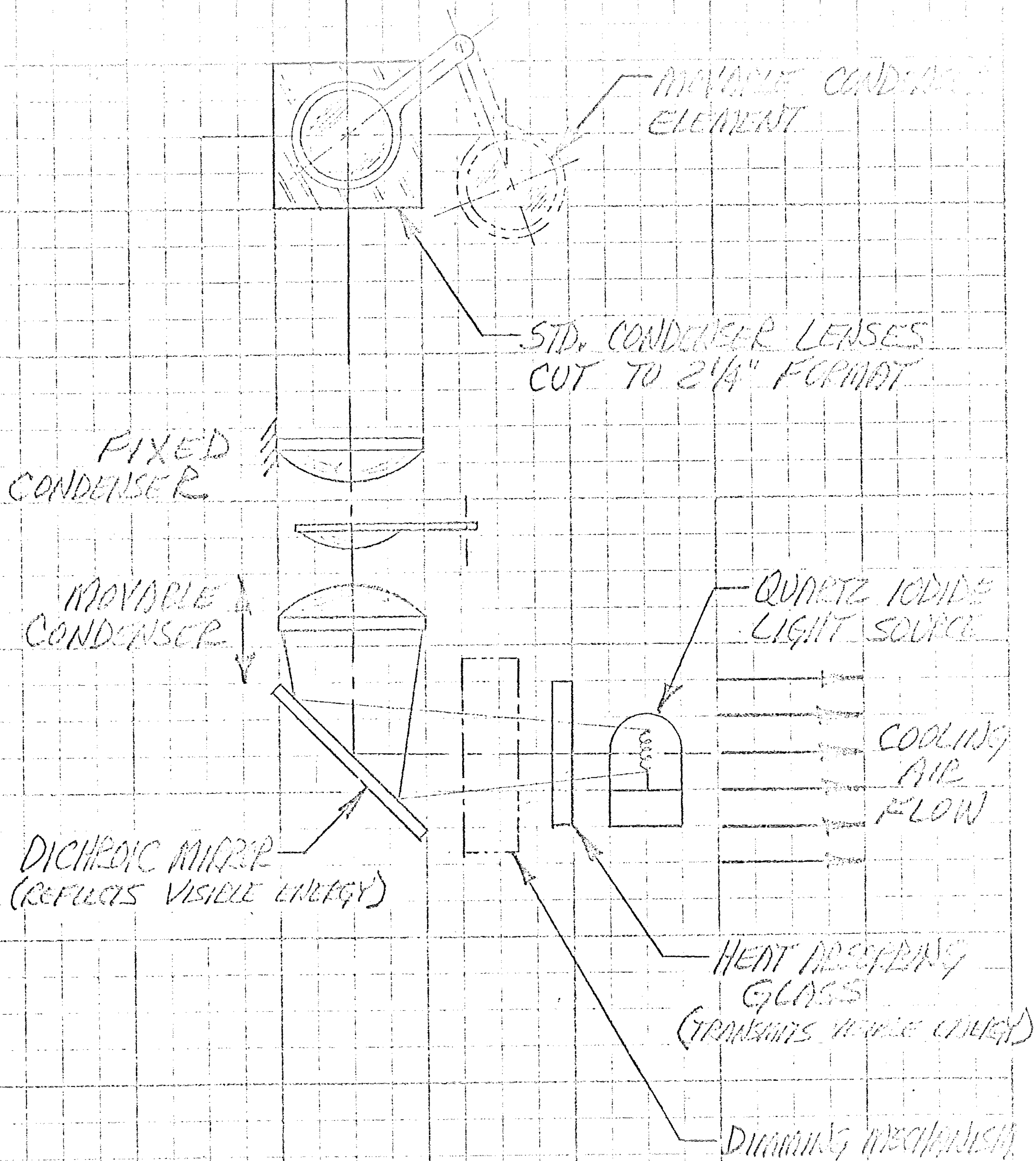


FIGURE 5.2 – CONDENSER

availability, etc., it is recommended that quartz iodine lamps be utilized as the standard light source for each of the four projection systems of the PMV.

5.4.3 Brightness

The rear projection screen brightness, as viewed from the position of the image analyst, should have a minimum acceptable luminance of at least 30 foot-lamberts at all magnifications for comfortable viewing under normal room lighted conditions. This luminance should be obtained with a 1.3 neutral density film in the projection gate, equivalent to 600 foot-lamberts open gate. In addition the screen should be evenly illuminated and, at no point, should the illumination deviate by more than 20 per cent. This factor is important because large variations in screen brightness will affect the image analyst's evaluation of the film material presented to him.

5.4.4 Viewing Screen

The recommended rear projection screen should measure 15" by 15" to adequately cover the 6X magnification of the 2 1/4" X 2 1/4" format. This size screen will comfortably fit in with the average operator's 60° vertical field of view to provide full viewing capability from as close as 60° (15in.)(.01745 radians/°)= 15.7". It should be noted that too large a viewing screen will make it difficult for the image analyst to be able to comfortably view the entire format and still be within easy reach of all controls. The viewing screen material should provide uniform luminance over its entire surface, with an open gate. It should not contribute any color or granularity to the projected image and should

should not degrade the contrast. In addition the screen material selected should be capable of resolving at least 43 lines per mm in addition to the brightness requirement.

5.4.5 Filters & Bandwidth Discussion

The selection of filters to be used in the PMV assumes that the duplicated positive film has been reproduced so as to exhibit a low minimum density on each of the records as well as a gamma which is greater than one (about 1.6). These constraints are necessary to produce adequate color discrimination in a multiband additive process. High brightness value is obtainable by keeping the minimum density as low as possible--equal to or slightly greater than the base plus fog level. A gamma of one on the reproduced positive will generate an identical one to one mapping from the object luminance domain into the density range. The result will be an accurate presentation of the scene to the human eye. In order to generate greater density differences and hence more saturated colors on the viewing screen, the gamma of the positive records must be greater than one. That is to say, along the straight line portion of the characteristic curve, a difference in log brightness will be represented by a greater density difference and the saturation of the color between any two points will have increased substantially.

In the selection of multiband filters for viewing (or synthesis of the imagery) it is necessary that three viewing filters be chosen with chromaticity coordinates of sufficient diagram is a maximum. The viewing filters should also be chosen so that the included triangle lies close to the yellow region since pure yellow exists in nature and cyan does not. The third condition for multiband additive viewing filters is that they possess sufficienct percent transmission to minimize the light source requirement.

One of these filters should have a dominant wavelength of 615nm ± 2nm and nominal chromaticity coordinates of (.68 ± .01, .31 ± .01) when measured with an illuminant "C" source. This filter should have a nominal bandpass of 120 ± 5nm and a peak transmission of 90% ± 1 %. The second filter should have a dominant wavelength of 470nm ± 5nm and nominal chromaticity coordinates of (.141± .01, .048 ± .01) when measured with an illuminant "C" source. This second filter should have a nominal bandpass of 140nm ± 5nm and a peak transmission of not less than 65%. The third filter should have a dominant wavelength of 540nm ± 2nm and nominal chromaticity coordinates of (.240 ± .01, .690 ± .01) when measured with an illuminant "C" source. This third filter should have a nominal bandpass of 130nm ± 5nm and a peak transmission of not less than 55%.

It would be possible to select filters which lie closer to the locus of pure color in the chromaticity diagram and hence have more area included in the color triangle. Consider such an alternate set; the characteristics of each combination (1,2,3 and 1A, 2A, 3A) are given in the following table:

FILTER	1	1A	2	2A	3	3A
DOMINENT COLOR	BLUE	BLUE	RED	RED	GREEN	GREEN
DOMINENT WAVELENGTH	470	450	615	645	540	539
CHROMATICITY COORDINATES	.141,.048	.153,.019	.680, .32	.71,.29	.24,.69	.22, .747
MAXIMUM TRANSMISSION	65%	50%	95%	92%	55%	13%

The chromaticity coordinates of these six filters are plotted below in Figure 5.3. It is obvious that 3A is more saturated than 3, that 2A is more saturated than 2, and that 1A is more saturated than 1. It is interesting to note however that the maximum transmission of 3A is only approximately 24% of #3. The maximum transmission of 2A is 97% of that for #2, and the maximum transmission of 1A is 77% of that for #1. This substantial decrease in the transmission characteristics of the more saturated filters is due to their chromaticity coordinates and the relatively small half bandpass which is required to obtain such purity. This decrease in transmission indicates that a substantially lower brightness level will be realized on the multispectral projection screen. The resultant color displayed on the precision multiband viewer should be of sufficient brightness to yield a chromaticity triangle of maximum area without sacrificing high brightness level.

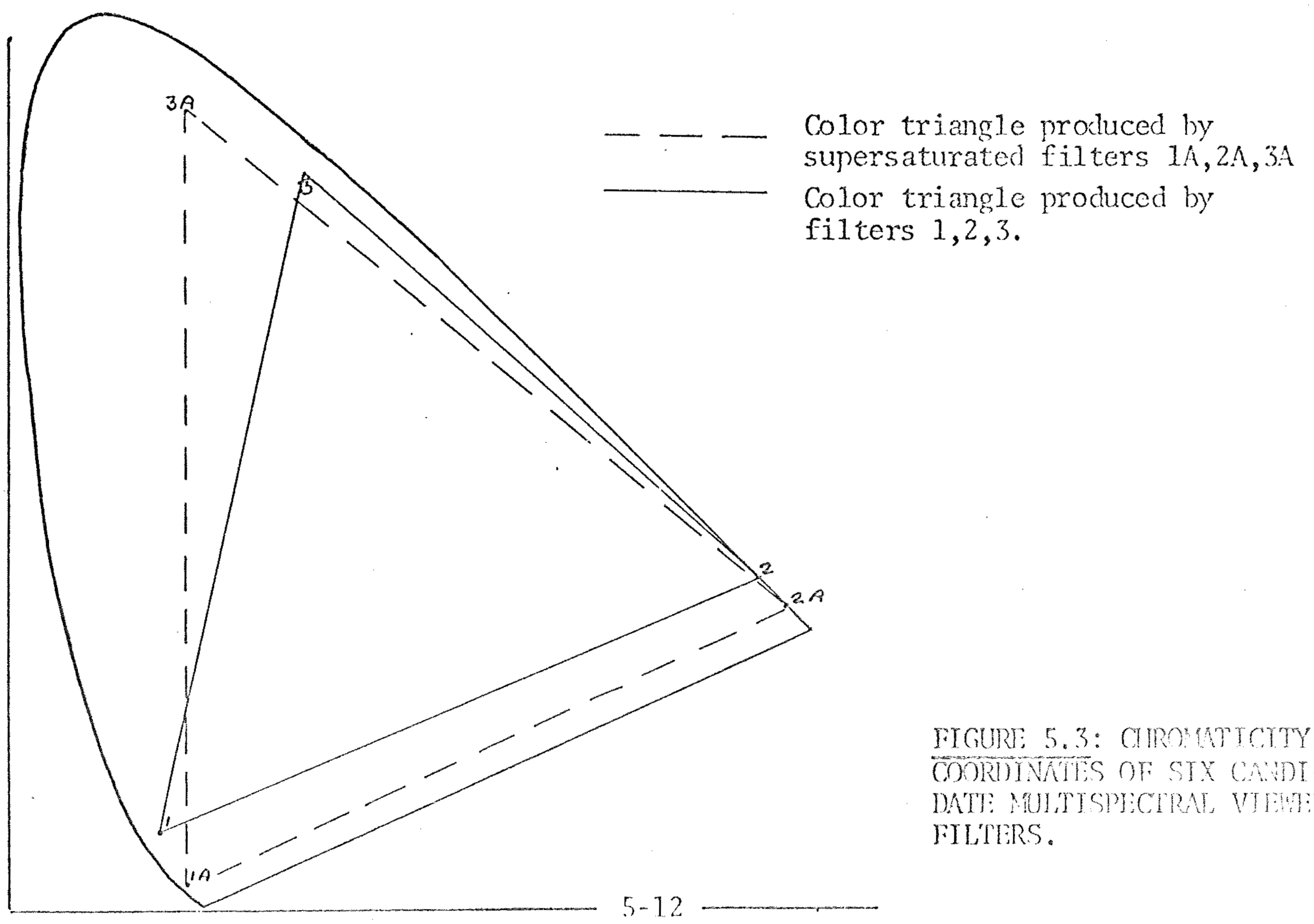


FIGURE 5.3: CHROMATICITY COORDINATES OF SIX CANDIDATE MULTISPECTRAL VIEWER FILTERS.

6. Registration Criteria & Error Analysis

6.1. Objective

The primary objective of the Precision Multiband Viewer is the superimposing of four spectral images on to a rear projection screen at various magnifications. To achieve effective superimposition, each element of each of the four images must be registered to each other to a specific degree of accuracy.

6.2. Registration Accuracy Requirement

The registration capability for the viewer was specified as "one-half of a resolution element (5 microns at 100 lines/mm) at the center of the image" in the Statement of Work for Contract NAS9-9489. This requirement is interpreted as being the quality of each of the four input images which is to be capable of being resolved when superimposed by the projection optics of the viewer. In general, this is considered to include magnification in order to see this fine degree of detail. Figure 1 is a graphic representation of the interpretation of this requirement for registration accuracy. The superimposed image projected on the viewer screen can also be considered as an aerial image, which could be viewed with microscope optics. It should be noted that the superimposed image of Figure 1, projected at 10 X magnification, possesses greater resolution than can be seen by the human eye. Therefore, additional power is required to exploit the data content of the input film.

6.3. Error Sources Affecting Registration

6.3.1 General

The error sources affecting the registration accuracy of the superimposed multiband image can be analyzed on the basis of their

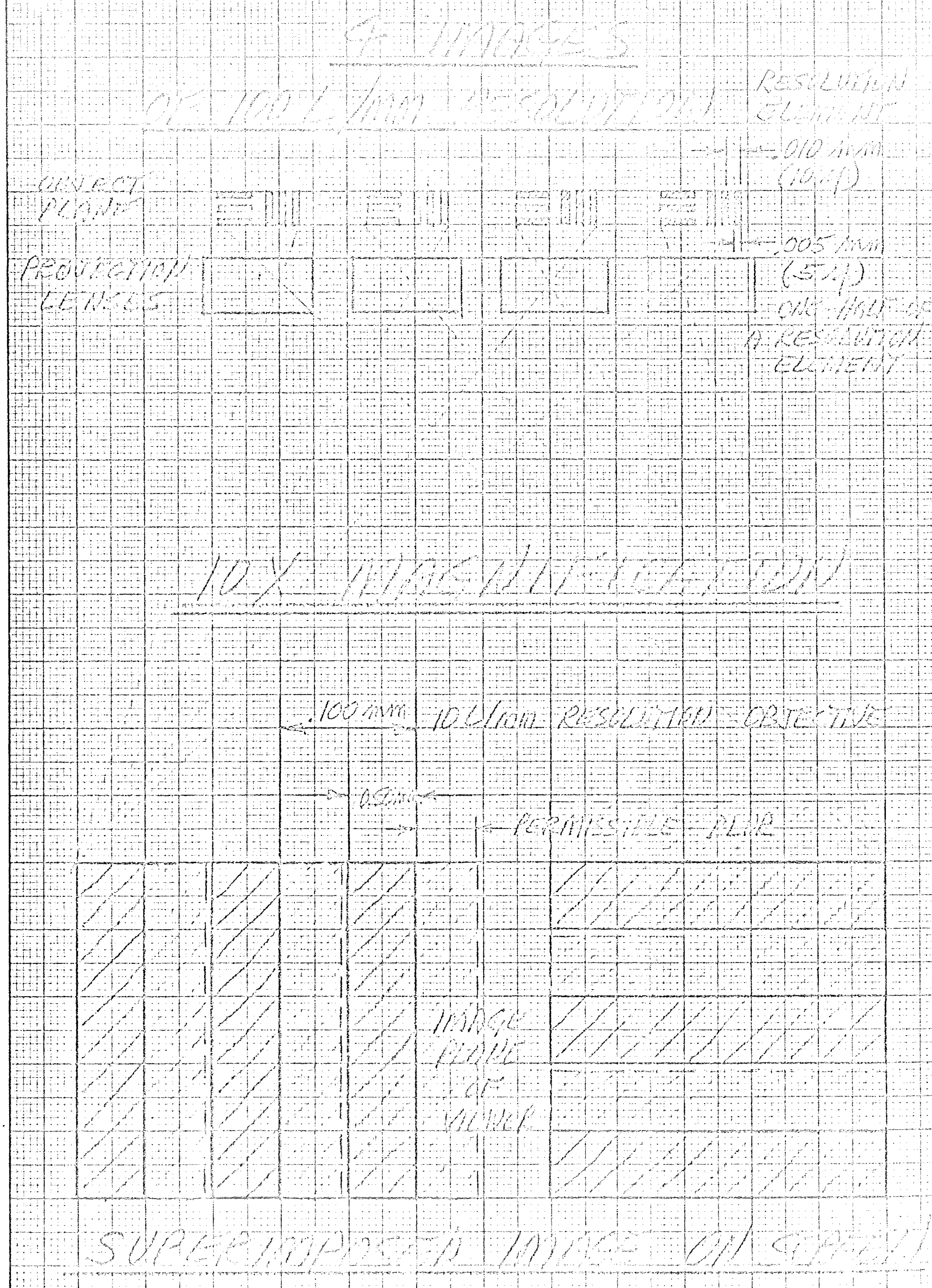


FIG. 6-1 - REGISTRATION ACCURACY

contribution relative to the practical realities of precision requirements. That is, some typical manufacturing or assembly tolerances will have a gross effect upon the registration accuracy when applied to some components parts, whereas the same tolerances applied to other components are not as significant. However, the effects of these secondary errors are still felt by the system and the analysis will attempt to determine the most practical method for eliminating or reducing these errors. Differential errors in the locations of specific image points within a film frame, relative to the other three film frames, are due to the following factors:

A. <u>Taking Camera Errors</u>

-EFL variation(scale); ΔX & ΔY

-Distortion; ΔX, ΔY & $\Delta\theta$

-Exposure time (vehicle/structural displacement); ΔX, ΔY & $\Delta\theta$

-Lateral displacement of film frame; ΔY

-Rotational displacement of film frame; $\Delta\theta$

-Film transport tension variation; ΔX

-IMC or transport speed variation; ΔX

-Alignment relative to other cameras; $\Delta\theta$

B. <u>Vehicle Errors</u>

-Roll; ΔX or ΔY

-Pitch; ΔY or ΔX

-Yaw; $\Delta\theta$

-Drift or crab angle variation; $\Delta\theta$

-Altitude (scale); ΔX & ΔY

C. Film Shrinkage & Stretch

-Shrinkage; ΔX & ΔY (mostly ΔY)

-Drying variation; ΔX

-Stretch due to high tension; ΔX

Regardless of the source or cause of the error, and the relative magnitude of the error, an evaluation must be made which can predict the resulting mean error related to the overall performance objective of the Precision Multiband Viewer.

6.3.2 Image Rotation (θ)

The effect of image rotation upon the registration accuracy can be quite significant, depending upon about what point the rotation occurs. The rotation of any one of the four input images relative to each other, or to some best fit registration of the other images, could be due to any number of causes; vehicle motion, camera orientation in vehicle, film alignment and tracking in camera, film alignment and tracking in viewer, etc. Consider a 70mm (2 1/4" x 2 1/4") film frame projected at 10X magnification. If this film frame is part of a standard film roll, the width of 70mm film is specified as 2.754", ±.002", according to USA Standard PH 1.10. Typical film track widths are specified to have a clearance of from .010 to .020 over the film due to standard tolerances on a specified dimension, parallelism tolerance, film width tolerance and provisions for a minimum clearance should tolerances fall on the low side. Figure 6.2 illustrates what would be the image rotation error, relative to the side of the film for a typical 70mm frame camera, with an approximately 3" long format plate. The skew angle for this typical set of conditions, for the worst case of film tracking is

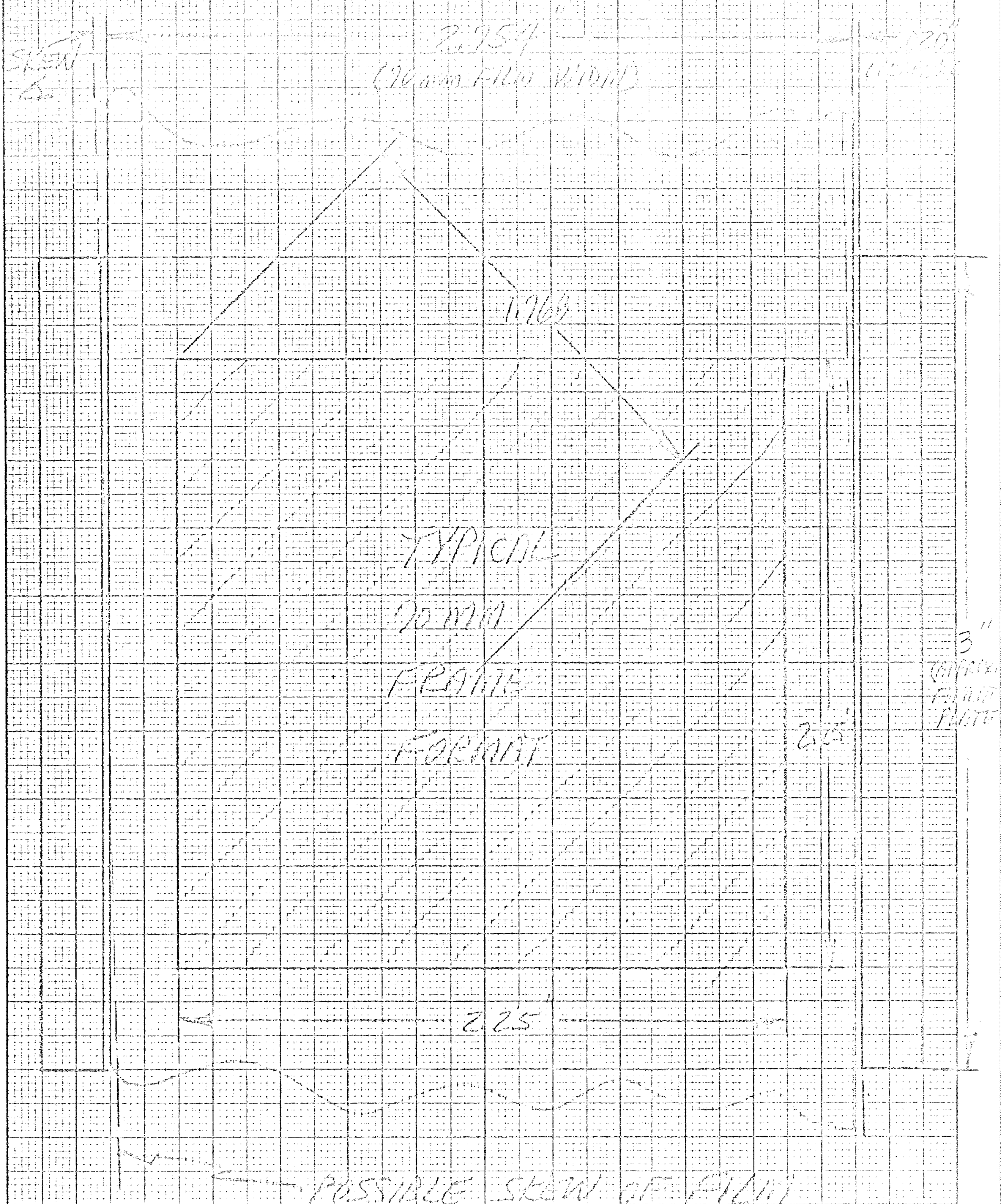

SKEW
2.354"
(70mm FILM WIDTH)
.120"
TYPICAL
70 MM
FRAME
FORMAT
2.25
2.25
3"
POSSIBLE SKEW OF FILM

FIG. 62

$$\tan \theta = .020''/3'' = .00667''$$

$$\theta = 23' \text{ of arc}$$

The corresponding angular displacement of imagery in the corners of the 2 1/4" x 2 1/4" format is .0267" for this worst case condition of image rotation only.

The effect of this image displacement due to angular rotation of the image, for the extreme corners of one film frame only, is to degrade the resolution from its original level of say 100 lines/mm to .8 lines/mm.

However, this type of image rotation is easily prevented for multiband photography applications by the design expedient of having a spring-loaded lateral retainer for the film, in both the camera and the viewer.

Another way in which the significance of this one error source can be evaluated is to use the resolution capability of the human eye as an alignment criteria. The average human eye has the resolution capability of one minute of arc or .000291" per inch. This can be viewed from the viewpoint of having four absolutely identical images aligned in rotation to each other within one minute of arc. However, the imagery in the corners of the 70mm frames can then be displaced from each other, or the theoretically perfect image, by .000291(1.768) = .00051". Therefore, with the best alignment possible by the unaided human eye (without magnification), the resolution of the combination of two theoretically perfect images is limited to 40 lines/ mm.

Consider a Precision Multiband Viewer which is simultaneously projecting the 70mm frame image from four (4) film rolls and it was just decided to look at the next frame. If all four film drives transported the next frame to the film gate without any perceptible lateral film motion to cause image rotation, the resolution capability of any superimposed image would still be limited to 40 lines per millimeter, referred to the input film. Another consideration involves the angular rotation capability which must be provided in the viewer to achieve the registration capability of 5 microns even at the center of the image. If the image rotation had occurred about a corner of the format, or has occurred for the entire format of a given frame, as for example the angular alignment of one camera relative to the other cameras, there would be an allowable displacement of 5 microns at the center. Refer to paragraph 3.1.2 Registration, of Contract NAS9-9489 Statement of Work. The angular rotation corresponding to this 5 microns is

$$\tan \theta = \frac{.005\text{mm}}{1.768 \text{ in } (25.4\text{mm/in})} = .00011$$

$$\theta = 23'' \text{ of arc}$$

The significance of this value is that it highlights the degree of positioning preciseness and stability which is required of each image rotation mechanism. In reality, an error budget will be established and the allowable error due to image rotation will be much smaller in magnitude so we can anticipate mechanisms capable of positioning to seconds of arc as being required. This introduces another factor relative to attaining a preciseness or resolution capability of this nature in the viewer's remote controlled mechanism. If it will be required to angularly position the imagery to seconds of arc, what will be the total range of angular positioning required of the mechanism? If, for example, a range of 5° is essential to cover the worst case condition, this is equivalent to 18,000 seconds of arc. The significance of this previous study relates to the establishing of feasible design criteria with the appropriate error budgets. For angular rotation, standard precision is considered to be 10 seconds of arc, high precision is considered to be 5 seconds of arc and ultra precision is considered to be 1 second of arc. Auto-collimators, interferometers, etc. extend angular rotation capabilities to 0.1 second of arc.

Consideration of the design of precision goniometers capable of repeatability to 1 second indicates that this would represent the ultimate obtainable without any limitations upon weight and size. Since 23 seconds of arc was computed as the maximum angular rotation error which would be acceptable if there were no other errors, it appears feasible at this point to establish 5 seconds of arc for this portion of the error budget which would not require a large amount of time to be spent in registering the superimposed image. This would result in a total angular positioning range to accuracy ratio of 3600 to 1.

6.3.3 Image Linear Displacement (X)

As with image rotation (θ), there are numerous error contribution sources which will displace the film imagery linearly (longitudinally relative to the film roll). In any case, regardless of what causes the specific image of one particular film frame to be displaced linearly in this X direction, the Precision Multiband Viewer requires remote control capabilities which will permit the reduction of these image displacement errors to the satisfaction of the overall system requirements. If a differential image displacement is caused by a transient or short time period variation in say, the IMC mechanism of the taking camera, or if the IMC mechanism of one camera relative to the others has a different speed factor in its servo, there will be specific differential displacements of portions of the imagery relative to the corresponding imagery on the other frames of the other film rolls.

Consider the effect of a typical 1 per cent IMC servo in the typical camera. In achieving image motion compensation, the film (with or without its platen) is driven, relative to the direction of flight, by a servo system (controlled by a V/H computer) so that the blurring due to relative ground motion during the exposure cycle, is minimized. While this exposure is being made, the closed loop servo drive is continuously changing its speed in response to the changing V/H signals. For a given finite time of say 0.001 seconds, which could correspond to some portion of the total exposure time, there is a variation in image displacement produced in the direction of flight, considered the X direction for most aerial cameras. The reference to a 1 per cent IMC servo refers to the accuracy in matching the ground vector during exposure, as responding to the V/H signals. Aside from lower film resolution, this type of error can result in a differential displacement of a portion of the imagery relative to its corresponding portion of imagery on the other three film frames.

Another small ΔX error can be attributed to the variable stretching of the film due to varying tensile force applied by the film transport drive, and even smaller ΔX variations due to minute differences in the temperature and humidity from film roll to film roll.

Another small ΔX error can be attributed to the permanent deformation or stretch in the film emulsion of each film roll, such as core curl, as the film passes over a roller or spool with too much tension. Consider the case of four separate film rolls which do not have the same condition, relative to film transport, as when all four images are on the same film roll. With well designed film transport drives where the optimized operational features require relatively rapid accelerations and dynamic braking, the tensile forces on the film become quite great. Typical tensile forces used are 1 lb per inch of film width. The neutral plane of a film wrapped around the spool cores or passing over rollers is subjected to deformation from the bending stress itself, the different moduli of elasticity of the base material, emulsion, gel backing, etc.; in addition to the variations in tensile force, as shown in Figure 3. A typical manifestation of the permanent deformation is the "core set", or "core curl", which is often seen on the inner layers of film wrapped on spools. This differential ΔX error can be ignored when all four images are close together on the same roll of film. Of interest are the mechanical properties of the film and those involving dimensional stability. These properties vary, within relatively small tolerances, from film to film. Consider one particular film type: Estar base aerographic film. Data on mechanical properties and dimensional stability of the film, the base, gel backing and emulsion are listed in the Manual of Physical Properties of Kodak Aerial and Special Sensitized Materials. The yield strength (S_y), the yield elongation (e_y) and Young's modulus (ε_β) for the base are:

$$S_y = 13{,}500 \text{ psi} \qquad \text{Ref: Table 5-1 of E-K Manual}$$
$$e_y = 5.5\%$$
$$\varepsilon_\beta = 680{,}000 \text{ psi}$$

All properties are measured at 70° F and 50% R.H. The most significant property for the computation of stress/strain relationships is Young's modulus of elasticity. The film base has a thickness of 0.004"

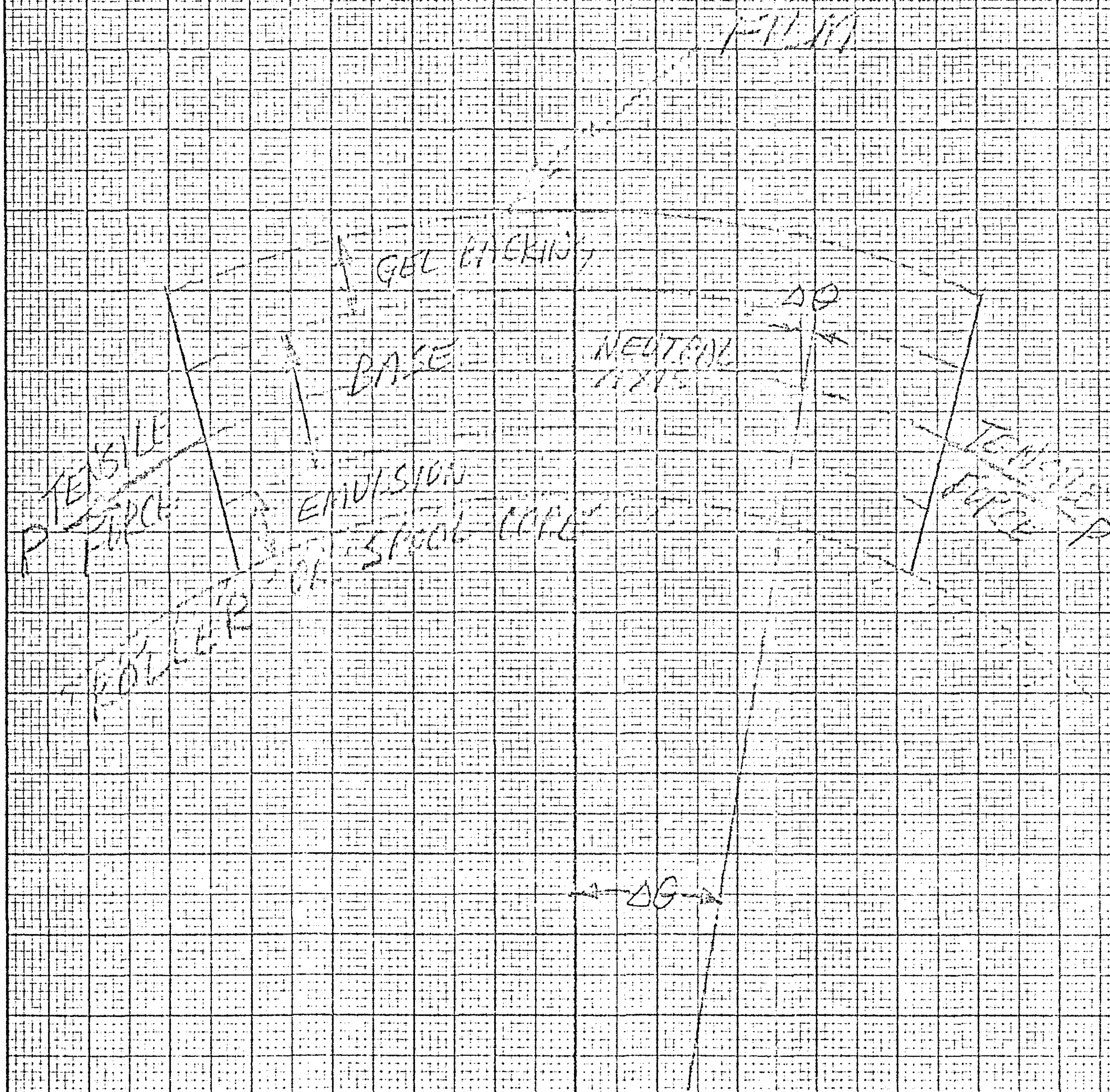


FIG. 6-2 – BENDING OF FILM ABOUT ROLLER

(±0.0002") and a width of 2.754". Gel backing thickness = 0.0002"and emulsion thickness is usually = 0.0003". The film elongation due to the tensile force in the film can be computed as follows:

$$e_{T.F.} = \frac{P}{Wt\varepsilon_{\beta}}$$

Where $e_{T.F.}$ = elongation of the film, inches/ inch

P = tensile force on film, lbs

W = width of film, inches

t = thickness of film base, emulsion & gel backing

ε_{β} = modulus of elasticity of base, lbs/in^2.

$$e_{T.F.} = \frac{2.75}{2.75(.0045)\ 680{,}000}$$

$$= 0.00033 \text{ inch/inch of film}$$

The corresponding stress in the film for this elongation, considering that only the base material would feel the strain, is

$$s = \frac{P}{Wt} = \frac{2.75}{2.75 \times .004} = 250\text{psi}$$

With the frame length of 2.25", the elongation of the film under the typical tension of 1 lb/inch of film width becomes 0.00073", or 18 microns, over the same frame. With 90 per cent of the cases considered to be 100 foot film spools, the variation in radius from an empty to a full spool would be almost 4 to 1 for standard film spools. This will result in a variation of tension on the film of 4 to 1 unless the film drive has a servo controller to measure film spool diameter and thereby provide a constant tension drive.

In any event, just consider the effect of a 1/2 lb variation in tension from one film drive to any of the others. This would result in an elongation of one image frame, relative to the others, of about 9 microns. Therefore, if all the other errors were eliminated and the images were identical and perfectly superimposed, if one 70mm film roll had 1 3/8 lb. more tension than the other, the imagery at the end of the 2 1/4 in. long frame would be elongated and misregistered by 9 microns.

Temperature and humidity variations can cause surprising changes in film length however, it is considered that for all practical purposes, the temperature and humidity is the same for all four film rolls and that all 4 film rolls are of the same material.

6.3.4 Image Lateral Displacement (ΔY)

The largest lateral displacement of the imagery which could occur is that due to the clearance, see Figure 6.2, which must be provided beyond the maximum film width expected, so that the film can be efficiently transported. This error is considered to have occurred in the taking camera and it is assumed that the Precision Multiband Viewer will employ springloaded film guides at the projection gate so that it will not contribute further to this particular error. It is considered, in this case, that the film was tracking perfectly and that no skewing, as discussed in 3.2, occurred. In actuality, there will probably be a certain amount of both errors ($\Delta\theta$ & ΔY) occurring however, for this analysis we will consider the worst case condition which could occur. Therefore, it is possible for one image on a particular film roll to be displaced as much as 0.020" from its corresponding image on another film roll.

Another significant error can occur in the framing or centering of the format plate or platen opening itself. Even for high performance sophisticated aerial cameras this usually falls under the standard manufacturing tolerance of ±0.005". Therefore, we can consider its worst case variation from one camera to another as being 0.010". Other significant errors which should be provided for by the lateral adjustment mechanism of the Precision Multiband Viewer are related to the mounting and alignment of the cameras in the vehicle wherein the image lateral displacement, relative to the other images could be due to linear and/or angular variations; the corresponding decrease in width which accompanies the increase in in-length or elongation when tension is applied; relaxation shrinkage or aging which, like the shrinkage resulting from processing, has a greater variation in the lateral dimension.

In almost all cases there is a differential dimensional change characteristic between the ΔX and the ΔY which is minimized by use of polyester base films which exhibit a high degree of uniaxialism.

6.3.5 Variations of Input Photography

With reference to the End Item Specification, Flight Hardware for Experiment S190, Multispectral Terrain Photography, MSC-KW-E-69, following are some of the pertinent specified requirements which define the expected input to the PMV:

"p.3-7(g) Optical Axis--The optical axis of the individual lenses shall be determined to within an accuracy of less than 10.0 arc seconds. When the lenses are mounted to the camera and the film platen is in place, the departure of the platen from the plane perpendicular to the optical axis of the lens shall have a total run out of less than 0.0002".

(h) Distortion--Lenses #1, #2, #3 and #4 will be matched for operation in their respective cameras and spectral regions in such a manner that when the optical axis of the lenses are parallel to each other to within 60 arc seconds (That is, when the optical axis can be moved with pure translation so that they intersect at a common point, they all lie within a circular cone of 30 arc seconds half angle). Image points within the field common to four camera-lens combinations will lie within a 20 tan θ micrometer (tangential dimension) by 5 micrometer (radial dimension) ellipse when the principal points of four photographic images coincide. (θ is the angular field position). Restating the requirement, the lenses will be so matched that plots of radial distortion versus field position for the four lenses when superimposed will have a distortion spread of less than 5.0 micrometers. The spread of similar plots for tangential distortion shall be less than 20 tan θ micrometers. This applies to all field positions within the 2 1/4 inch by 2 1/4 inch format.

In addition to the above, the maximum allowable radial distortion is 50.0 micrometers. The maximum allowable tangential distortion is 5.0 micrometers. The axis of zero tangential distortion of the lenses as mounted on their respective cameras shall be parallel with the curves of maximum distortion all oriented the same way. This distortion matching is to be achieved when the lenses are used with an aperture ratio of f/2.8, f/4 and f/5.6. The above distortions are not calibrated distortion, but are measured distortion.

(i) Lens-Film Resolution --The static lens-film-filter-camera performance that shall be provided is specified graphically in Figure 4. The resolution values are in line pairs per millimeter at the specified contrasts. (Contrast is defined as the ratio of the target bar radiance

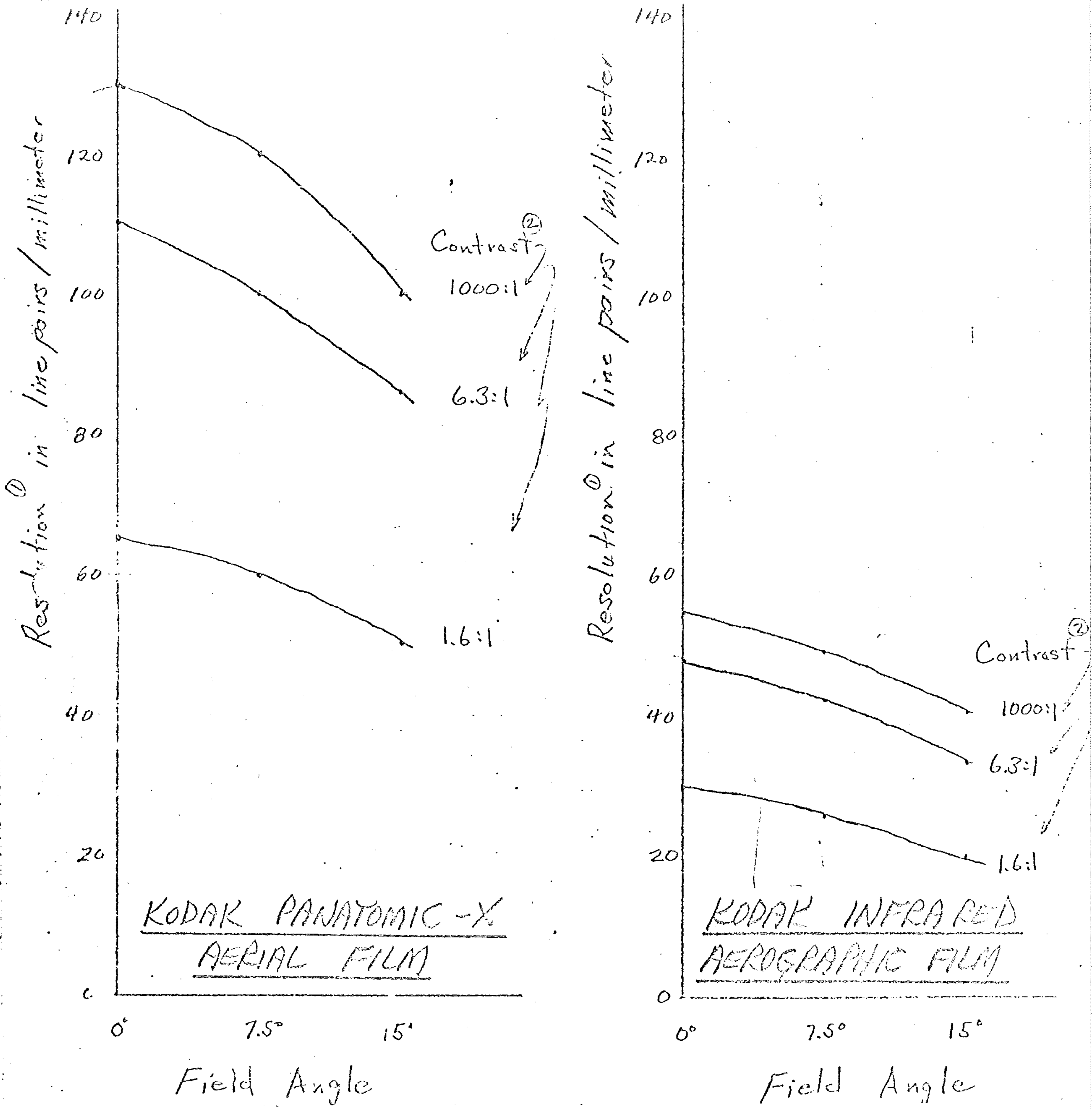


FIGURE 6-4- LENS-FILM-FILTER-CAMERA RESOLUTION

Note 1° Resolution is the geometric mean of the radial and tangential resolution as determined using procedures of Mil Std 150A

Note 2° Contrast is defined as N_{max}/N_{min} where N_{max} is the maximum radiance in the target and N_{min} is the minimum radiance.

to the target space radiance.) The resolution numbers are to be obtained using targets of the $6\sqrt{2}$ Mil-Std. 150 A type. That is, the dimensional layout and geometrical configuration of the targets shall be that of the USAF 1951 Resolving Power Test Target with a cross in the center of the pattern array for use in evaluating the distortion characteristics. The resolution values shall be obtained using Mil-Std. 150 A methods. The performance shall be verified along eight radial lines in the format which are spaced 45° apart. The specified resolution numbers shall be obtained with each of the cameras (with the respective lens-film-filter combinations) in the same focal plane in which the distortion and the transmission requirements specified herein are met."

The significance of repeating the specified requirements of the cameras is evident in that it defines the inputs to the PMV. Figure 6.5 is a graphical representation of the preceding to help define and clarify the specification of allowable distortions for the camera since comparable error sources exist for the viewer. Without resorting to a detailed error analysis of the camera, the most significant data item of the input photography specification is the distortion matching of the four lenses, so that when superposed, radial distortion spread shall be less than 5.0μm. The spread of similar plots for tangential distortion, as shown in Figure 5, works out to be 5.36μm for the 15° field angle corresponding to maximum coverage. Since the PMV will be tested with calibrated targets measured to an accuracy of 2μm (the readily available present state-of-the-art) the results will be more meaningful on a quantitative basis.

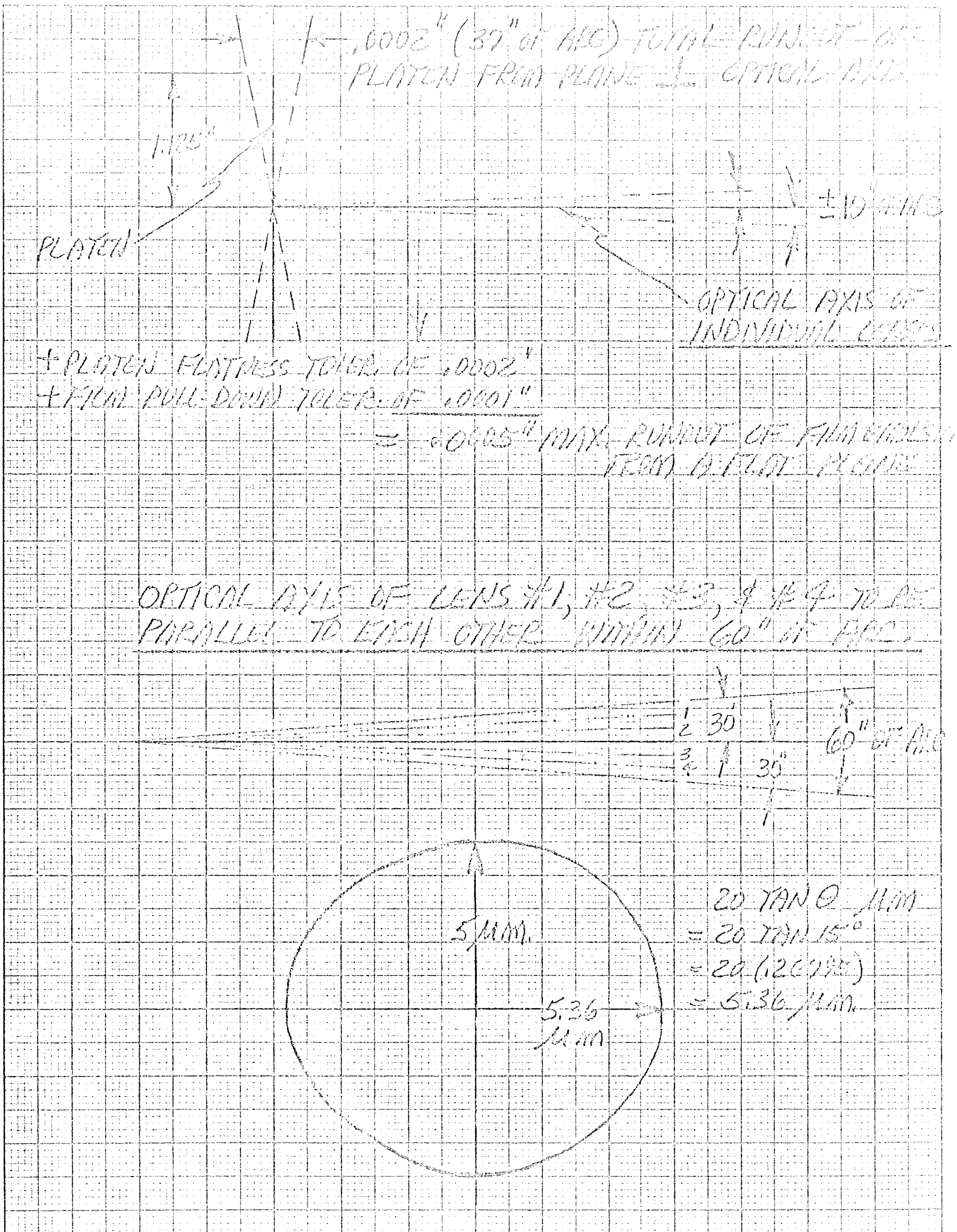


FIG. 6-5 - VARIATIONS OF INPUT MERIDIAN

6.3.6 Scale Variations (ΔZ)

The focal lengths for each of the lenses is considered to be the same within the constraints of the specified parameters however, there could be appreciable errors at the edges of the film format as indicated by the summing of the specified errors noted at the top of Figure 5. Consider a nominal 6" focal length lens with all the variations occurring in any one of the four cameras. The maximum run-out of the film emulsion, from its theoretically zero error position, of .0005" can be added to the worst case differential variation, 10" of arc, for a total internal or individual camera image displacement equivalent to 1'-53" of arc. With an allowable camera to camera optical axis alignment error of 60" of arc, it is possible for imagery at the edge of one camera's format to be simultaneously exposed with imagery in an adjacent camera while angularly shifted a total of 2'-53" of arc. With a 6" nominal focal length lens and the nominal 15° coverage this can be graphically illustrated as shown in Figures 6.6 and 6.7. Figure 6.6 illustrates the effect (exaggerated) of a 60" of arc optical axis misalignment of the respective cameras, or a circular cone of 30 arc seconds half angle. As can be noted from the graphical presentation, there are significant variations in X and Y of the image location within the film frame format with much less significant variations in the scale or size of the image, Z. The height H and the focal length F essentially remain unchanged and the object/image size is thus related to the cosine of the angular deviation, which is unchanged for up to ten minutes of arc. Without repeating the rigorous mathematics of analytical photogrammetry, we can more easily refer to the highest state-of-the-art photogrammetric

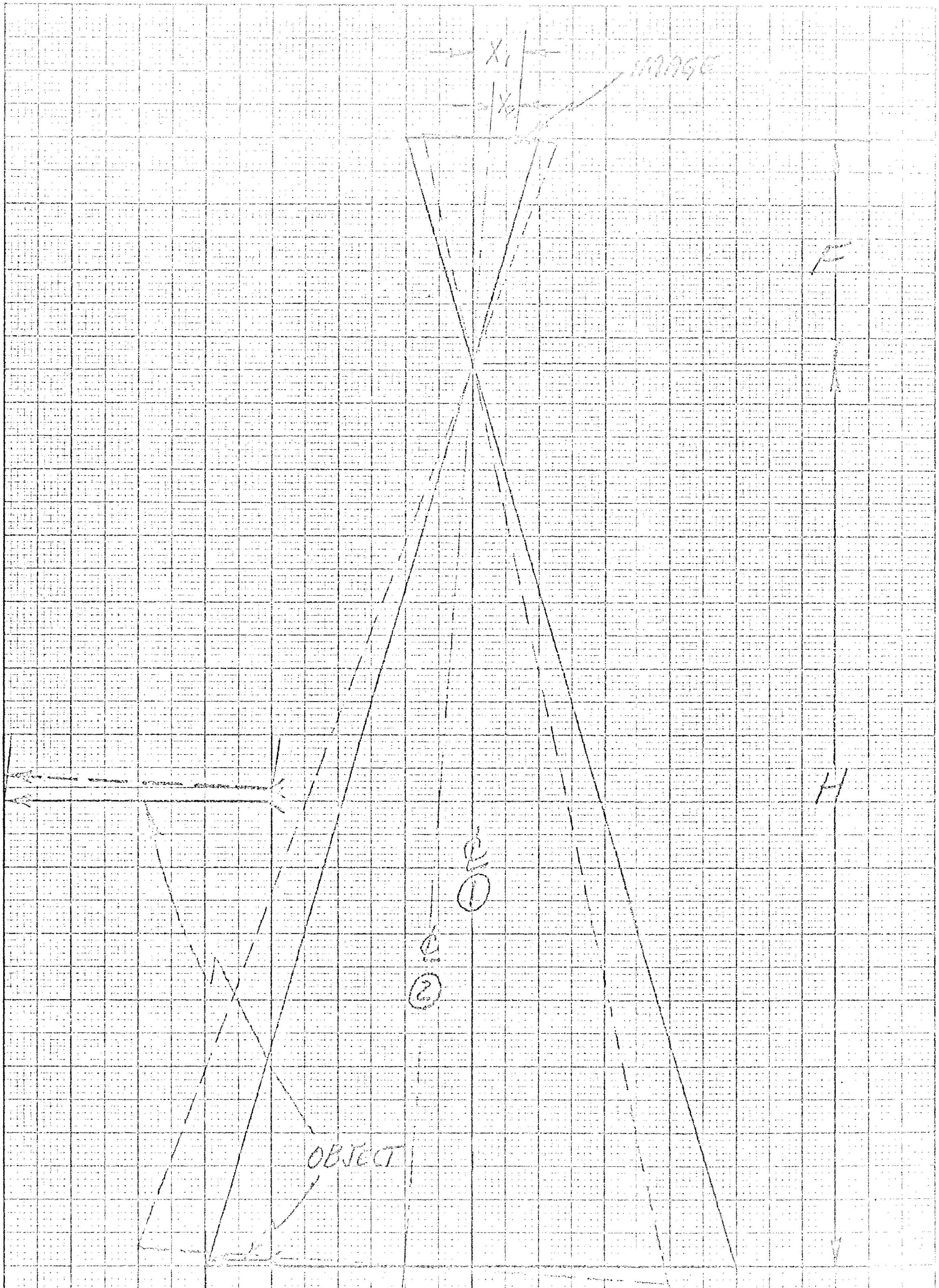


FIG. 6-6 - EFFECT OF CAMERA AXIS MISALIGNMENT requirements as an analogous comparison. Consider the most sophisticated mapping camera systems in use today, wherein the pointing accuracy or verticality of the camera is most critical in order to eliminate the need for rectification. These mapping camera systems employ gyro stabilized positioning mounts to maintain and steady the optical axis of the camera. Typical performance of these systems is to hold the camera's optical axis within a cone of 15 minutes of arc half angle with the highest attainable repeatable performance being 6 minutes of arc half cone angle. Therefore, the criteria of 30 seconds of arc half cone angle would not cause significant degradation in superposing the imagery by virtue of the scale variations. Figure 6.7 illustrates the physical relationship of the film emulsion plane relative to the optical axis. The worst case condition for all errors such as perpendicularity to optical axis, platen flatness, film pull-down, etc., is considered to result in a misalignment of 1'-53" of arc. The change in size from the theoretically perfect image, X_1, to the distorted image, X_2, can be resolved into two separate errors, as shown in Figure 6.7. The first variation of X_1 is represented by X_1' and it is an enlargement of X_1 due to the film emulsion being located some distance d behind (in this case) its theoretically ideal position. At the other end of the platen it is a reduction. The second distortion, from X_1' to X_2 is not a uniform change and is unidirectional depending upon the direction of tilt. The significance of this variation depends upon the magnitude of the resulting distortion. With a 6" (nominal) focal length lens, the worst case condition for the specified tolerances would result in a variation of approximately .0005"/6" ≈ .01 per cent. The effects of relief in the subject matter will increase

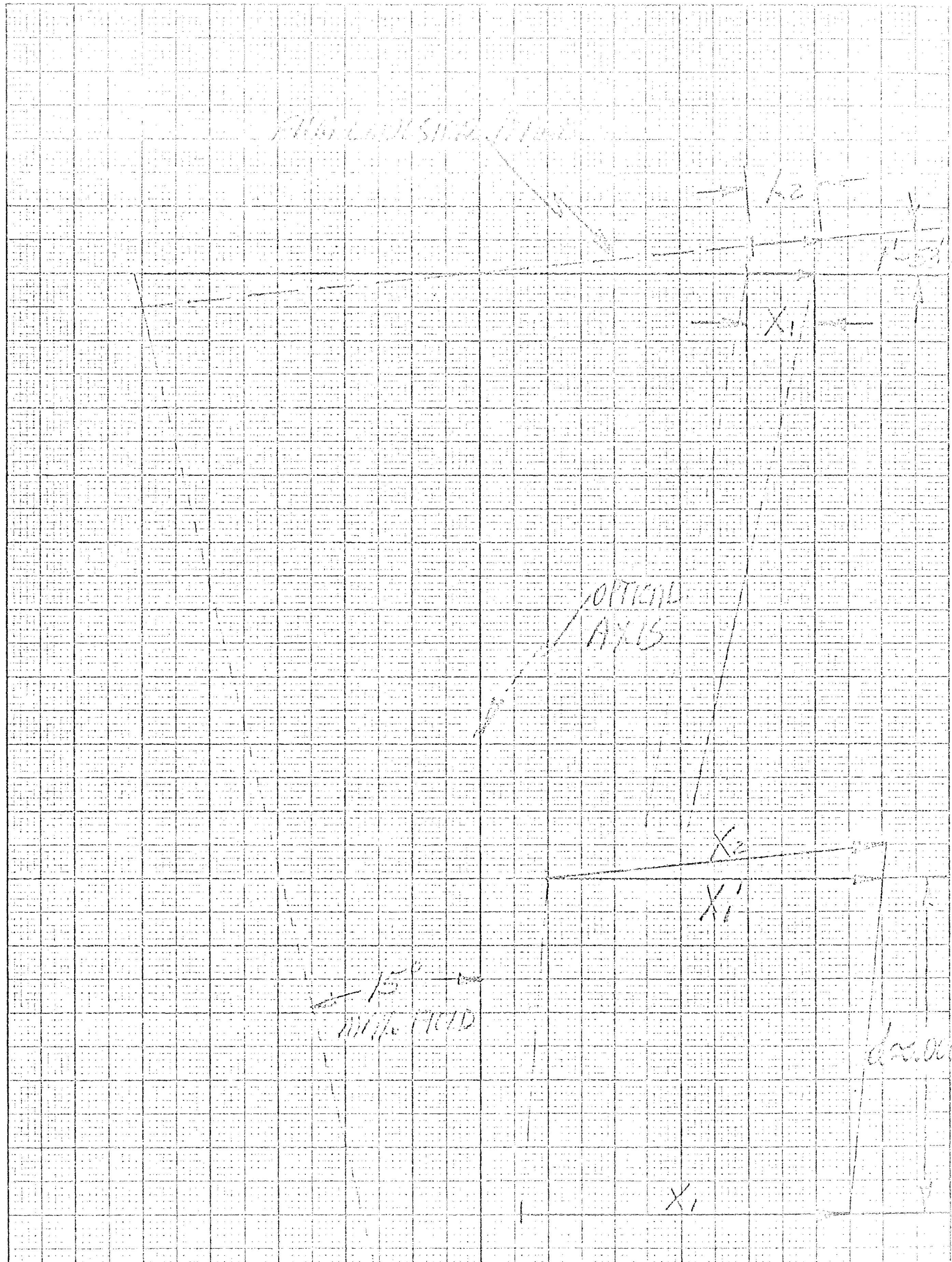


FIG. 6-7- FILM EMULSION PLANE MISALIGNMENT the distortion but this factor, like tilt, affects the metric accuracy from the overall photogrammetric viewpoint. The emphasis in this analysis is to investigate those distortions and variations peculiar from camera to camera within the total system.

Consider a finite image at the edge of the format for each camera. In one camera we can consider the tolerances and variations as all falling on the low side whereas they all fall on the high side for the next camera. With a finite image size of say 10mm, as representing largest size detail object of interest, the worst case scale variation (ΔZ) would be .01 per cent (10mm) or 1μm. This can be considered as an insignificant change in size and would not degrade the expected quality of the superimposed image.

6.3.7 Angular Rotational Variations of Optical Axes

The angular variations of the input optical axes can be considered for the most severe and critical condition which would occur when the input photography was exposed at different times. In this case gross errors, related to the aircraft's roll, pitch and yaw, would seriously complicate the registration of the four images. The logical assumption for multiband photography is that the four frames to be superimposed in the PMV were "nominally" exposed simultaneously. A related assumption is that all four cameras are fixed mounted together upon one homogeneous stiff structure with no relative deformation occurring during the exposure period. This, in essence, eliminates all dynamic errors related to the camera installation and vehicular performance during exposure. The remaining angular rotational variations are those due to variations in exposure time due to different film/filter combinations and variations in time constants, pulse rise times and decay, etc., from camera to camera. The worst case condition for shutter speed and synchronization is considered to be 4 milliseconds; ref. 3.1.1., 2.4.1 a. (5) (c) Shutter Synchronization, p.3-10 of Spec. MSC-KW-E-69 and 3.1.2.5.2 Intervalometer, p.3-18. With an orbital altitude of 220 nautical miles and 6" focal length lenses, the scale of the film is

$$S = \frac{6 \text{ in}}{220\text{nm}\left(\frac{6080\text{ft}}{\text{nm}}\right)\left(\frac{12\text{in}}{\text{ft}}\right)} = 1:2,675,000$$

The orbital velocity for an altitude of 220 nautical miles is about 17,500mph. The image displacement on the ground, due to a variation in exposure synchronization of 4 milliseconds is

$$D = \frac{17,500\text{mi}}{\text{hr}}\left(\frac{5280\text{ft}}{\text{mi}}\right)\frac{(.004\text{sec})}{\left(\frac{3600\text{sec}}{\text{hr}}\right)} = 102.67\text{ft}$$

The image displacement on the film is

$$\frac{102,67\text{ft}}{2,675,000}\left(\frac{12\text{in}}{\text{ft}}\right)\left(\frac{25,400 \text{ microns}}{\text{in}}\right) = 11.8\text{microns}$$

This variation of almost 12 microns can occur between cameras synchronized to an accuracy of 4 milliseconds and only represents the variation due to the motion of the ground vector. This variation can be considered to occur in either X or Y, or componenets of both, depending upon camera axis orientation to the ground track. Other variations can occur during the 4 millisecond synchronization error which are related to the vehicle's orbital steadiness. Throughout the flight, the vehicle is stabilized with respect to the ground vertical by thrusts from the gas servo-systems.

These low power positioning actuators continually apply small corrective torques to maintain the orientation. This results in the cameras' axes being maintained vertical within certain stabilization (amplitude) and steadiness (rate) constraints. Of these two factors, the steadiness constraints are the most significant and are worthy of evaluation. There are three mutually perpendicular axes about which the vehicle is stabilized. These are its roll (ϕ), pitch (ω) and yaw (κ) axes. Since the vehicle's dynamic characteristics are unknown at this time an analysis will be made on the basis of the specified parameters and determining what is the maximum permissible steadiness rate which will permit attaining the specified parameters. For the cameras we have the following:

focal length = 6"

shutter speed = 1/250 sec(4milliseconds)

resolution objective = 130 l/mm (Figure 6.4)
(of lens-film)

Using the Curves of Resolution versus Stability, Figure 8 of Hycon Manufacturing Company's "Aerial Photographic Reference Handbook", we find the maximum allowable stabilization rate, or steadiness, is 6×10^{-3} rad./sec.(0.34°/sec). It should be noted that this relatively low rate, or high degree of steadiness, corresponds to nominal performance obtained with present state-of-the-art stabilized camera mount performance of manned reconnaissance aircraft.

6.3.8 Viewer Variations of Optical Axis

Aside from the location of the input film imagery, and its variations from film roll to film roll, there are other variations of the optical axis which can occur within the viewer. The basic requirement is that once each of the optical axes has been determined, they can be aligned to each other with a high degree of accuracy. It is assumed that this alignment of all the optical systems is done with each system's optical elements (lenses, mirrors, glass platens, etc.) fixed and optimized for minimum aberrations. Another consideration inherent in the basic design of this type of optical instrument is that the support structures and all material used, be absolutely stable and that there be no dimensional changes resulting from variations in time, temperature, humidity, etc. Therefore, all materials used should be completely annealed and stress relieved after machining and all optical components and support structures should be analyzed against creep, relaxation and other minute and long time duration dimensional variations. Adjustments of the individual optical projection system elements can be made after the particular optical axis is oriented but care must be taken to ensure the stability of these adjustments.

6.3.8.1 Mirror Considerations

Consider the effects of a mirror used in the projection system to fold the optical path. The mirror must be flat to within one wavelength to ensure equal reflection in both the X and Y axes so that no astigmatic variations occur. In order to attain a high degree of flatness the thickness must be great enough, relative to its size, so that the flatness is maintained and is not affected by its mounting position orientation and mounting or clamping forces. Adjustment mechanisms should have a fine degree of control or precision since an angular adjustment of

1 second of arc, of the mirror, results in 2 seconds of arc displacement of the image. Correspondingly, the clampings or fixing after the adjustment is made should not change the angle.

6.3.8.2 Screen Considerations

Since all four images are projected upon a single screen it is not feasible to have the screen as an adjustable component of the projection system. Therefore,it has been considered that the input film plane or projection gate is adjustable even though it incorporates a much greater degree of complexity and secondary complications. The primary essential requirement of the projection screen now becomes flatness. Since the screen is on the long conjugate side of the projection system its requirements are not as exacting. However, unlike simple projection systems, the PMV has four separate images projected upon the screen. Since the four individual systems require some offset from the common center-line, as shown in the top of Figure 6.8, there are some angularities to be considered. As can be seen from Figure 6.8, the ratios of image to object distances ($A_1^{'} O_1/A_1O_1$ versus $B_1^{'} O_1/B_1O_1$) remain constant and therefore, the size of the images $B_1^{'}C_1^{'}$ and $B_2^{'}C_2^{'}$ will remain the same so that no registration problems will result. Also, it is considered that in the distortion matching of the individual lenses, the particular lenses selected would have been optimized for the particular off-axis angular presentation required by the design. There is a resulting variation in the resolution or image quality with respect to the images of A and B.

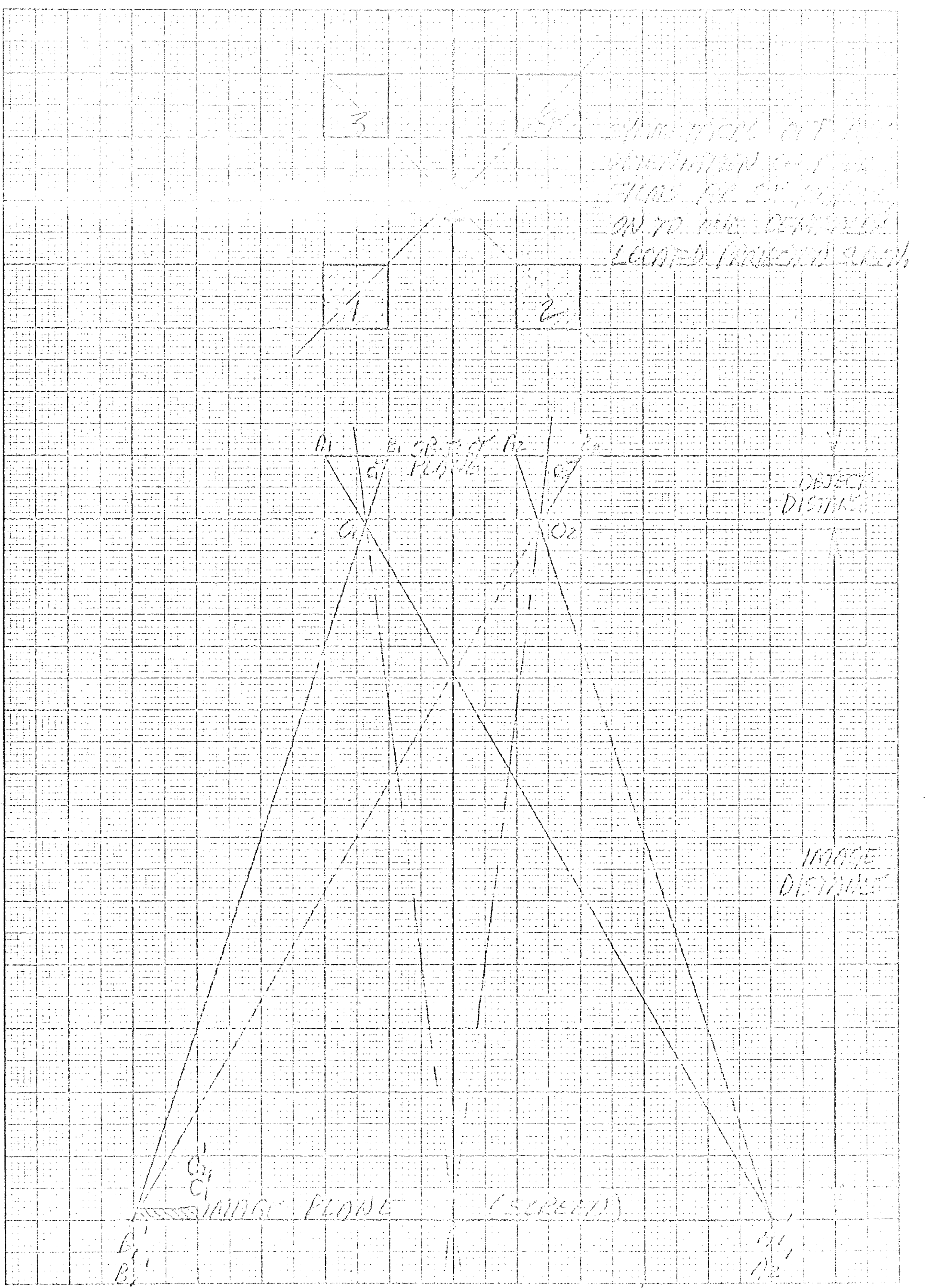


FIGURE 6-8-OFF-AXIS ANGULARITY OF OPTICAL AX

Theoretically, for an optimized image the angularity would result in degraded resolution for imagery at the ends of the format, A and B, whereas imagery along the central portion of the format would be unchanged. Again however, if the four lenses are selected and matched from a large enough sample, and this selection is done under a simulation of the design conditions, this additional error source can be minimized.

6.4. Error Summary

6.4.1 Image Rotation Error (θ)

With aided viewing (magnification) and an image rotation mechanism capable of repeatable positioning to within 5 " of arc, the residual registration error is approximately 1 micron.

6.4.2 Image Linear Displacement Errors (X and Y)

Precision linear displacement mechanisms for both X and Y can reduce the registration errors to the micron level with appropriate viewing and control capability provided to the operator.

6.4.3 Scale Variations (Z)

The expected scale variations was calculated to be .01 per cent which, when reflected to the largest size detail object of interest of 10mm, is resolved to be 1 micron. Even if applied across the entire format size of 2.25", would only result in a differential variation of 5.6 microns for the worst case condition. Therefore, if the values specified in the camera specification are met, it is not even necessary to provide an adjustment or means of correcting for this small an error.

6.4.4 Optical Axis Variations

Even though the camera specifications are realistically stringent and exacting, the possible variations of the optical axis can result in image displacements amounting to 12 microns. These image displacements can be in either X, Y or θ with respect to one film frame's format relative to another, or the others. These errors will have to be accounted for by the operator as three (3) registration adjustments because of logical exposure time variations. If all the imagery were exposed through one single shutter and had the exact same exposure times, these errors would be eliminated.

7. PRELIMINARY SPECIFICATION, RG 321-S, FOR PMV

7.1 Scope

This specification defines the design of a Precision Multiband Viewer, hereinafter referred to as PMV. The PMV is to be used for the screening and precision analysis of multiband photographic imagery obtained with multiband photographic systems to be used by the NASA. The PMV shall be installed at the Manned Spacecraft Center and will be available for use by the Earth Resources User Agencies and Principal Investigators. The PMV shall be designed to accommodate, as possible, multiband imagery obtained from other camera systems.

7.1.1 Function

The PMV shall be capable of superimposing four spectral images through optical projection means to the accuracy specified herein. The capability for varying the hue, intensity and saturation of the resultant image shall be provided in accordance with the parameters specified in this document. A capability shall be provided for recording the superimposed image on color film for future reference.

7.1.2 Principal Parts

The PMV shall be of a modular design, constructed as an assembly of the following sub-system modules, so that advancements in the state-of-the-art of the various technologies employed, can be effectively incorporated at some future date:

Sub-system Module	Paragraph
Display & Control Sub-system	3.4.2
Illumination & Filtering Sub-system	3.4.3

Film Transport Sub-system	3.4.4
Precision Registration Sub-system	3.4.5
Projection Optics Sub-system	3.4.6
Cooling Sub-system	3.4.7
Image Recording Sub-system	3.4.8
Structural Support Sub-system	3.4.9

Each modular subsystem shall be designed and constructed so that the specified performance requirement shall be met for both the modular subsystem and the assembled viewer system. The capability for future growth and modification shall not be construed to qualify the performance objectives.

7.1.3 Classification

The PMV shall be a flexible laboratory model designed for maximum versatility. It shall be designed around off-the-shelf hardware, wherever possible, and all techniques involved must be within the current state-of-the-art.

7.2. APPLICABLE DOCUMENTS

7.2.1 General

The following documents, of the issue in effect on this date, form a part of this specification to the extent specified herein.

Specifications

MIL-F-14072 Finishes for Ground Signal Equipment

MIL-H-27894 Human Engineering Requirements for Aerospace Systems & Equipment

MIL-M-26512 Maintainability Requirements

RG-321-ATS Acceptance Test & Calibration Specifications for the PMV

MIL-R-27070 Reliability Requirements for Development of Ground Electronic Equipment

Standards

MIL-STD-150A Photographic Lenses

MIL-STD-24343 Spool, Aerial Roll Film, 70mm

FED-STD-595 Colors

7.2.2 Outline & Installation Drawing

This drawing forms a part of this specification and shall be supplemented by the necessary interface and operational requirements, which is dependent upon NASA Earth Resources planning, which will be supplied by the NASA. The dimensions specified in this drawing are design goals. Any design exceeding these dimensions shall be reviewed by the NASA/MSC technical monitor.

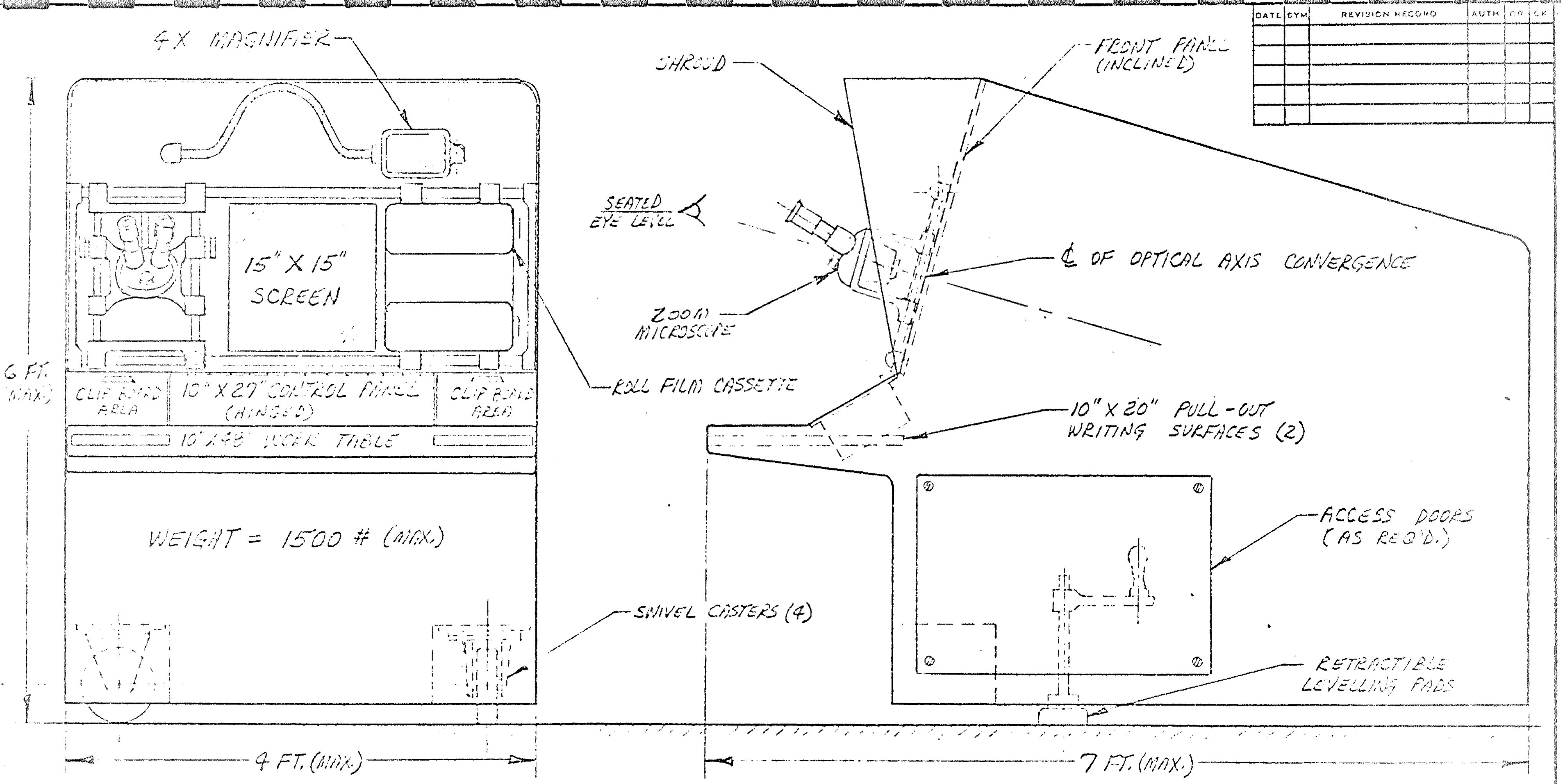
RG-321-D1 Precision Multiband Viewer, Outline Drawing

RG-321-D2 Precision Multiband Viewer, Control Panel Drawing

7.3. REQUIREMENTS

7.3.1 Preproduction Drawings

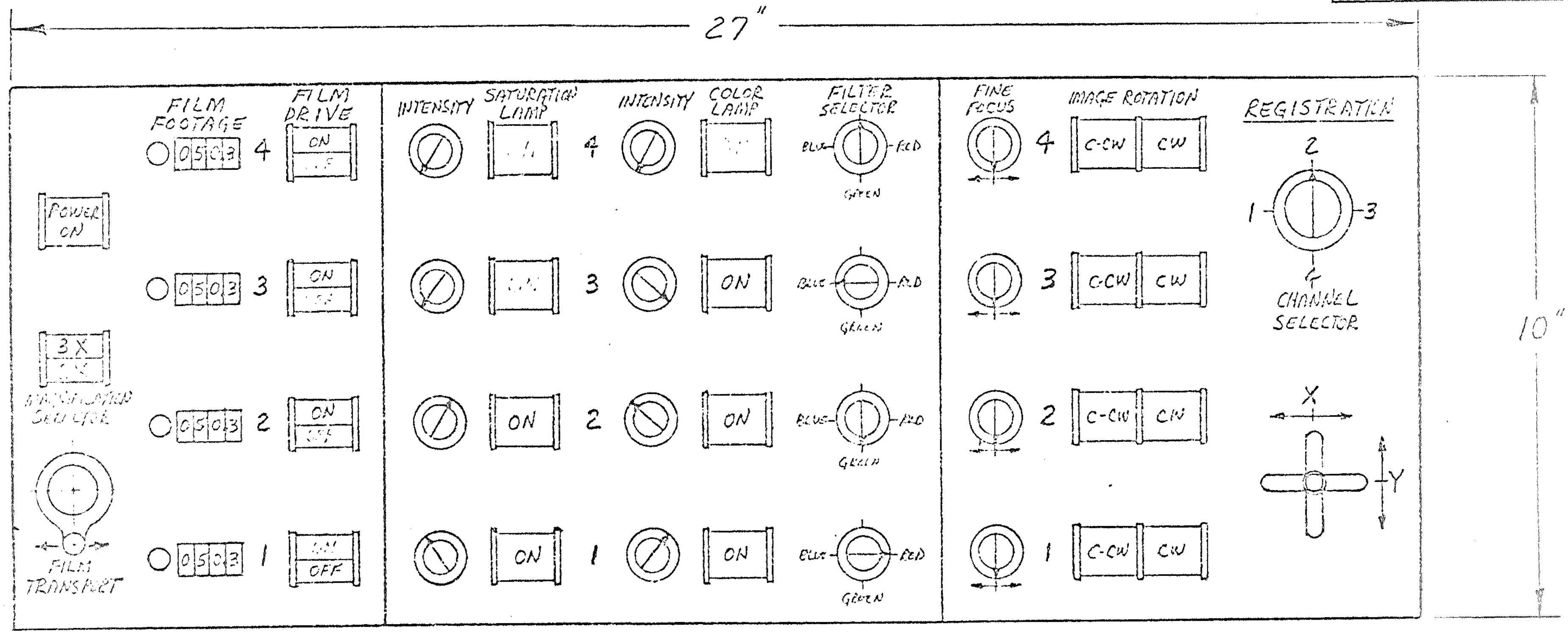
This specification provides for the criteria defining how the manufacturing drawings are to be made. The drawings shall be of good commercial practice, no freehand drawings or sketches shall be furnished. Schematic and wiring diagrams shall be provided which fully depict all the necessary electrical data and interconnections for maintenance and repair, as well as manufacturing.



DRAWING NO. RG-321-D1

PRECISION MULTIBAND VIEWER OUTLINE DRAWING

TOLERANCES (EXCEPT AS NOTED)	REF: PRELIMINARY SPECIFICATION RG-321-S		
DECIMAL ±		SCALE 1/10	DRAWN BY / APPROVED BY
FRACTIONAL ±	TITLE PRECISION MULTIBAND VIEWER OUTLINE DRAWING		
ANGULAR ±	DATE	DRAWING NUMBER RG-321-D1	



DRAWING NO. RG-321-D2 PRECISION MULTIBAND VIEWER CONTROL PANEL

DATE	SYM	REVISION RECORD	AUTH	DR	CK

TOLERANCES (EXCEPT AS NOTED)	REF: PRELIMINARY SPECIFICATION RG-321-S		
DECIMAL ±		SCALE 1/2	DRAWN BY / APPROVED BY
FRACTIONAL ±	TITLE PRECISION MULTIBAND VIEWER CONTROL PANEL		
ANGULAR ±	DATE	DRAWING NUMBER RG-321-D2	

7.3.2 Parts & Materials

In selecting the parts and materials, fulfillment of the design requirements shall be the prime consideration.

7.3.2.1 Standard Parts

MS and AN standard parts shall be used to the greatest extent. The parts shall be identified on all drawings by their MS or AN part number.

7.3.2.2 Commercial Parts

Suitable commercial parts may be used whenever approved standard parts are not available to meet the design requirements or to support delivery.

7.3.2.3 Materials

Materials used shall be of good quality, entirely suitable for their intended purpose. Materials shall be free from defects and imperfections that might affect the performance, serviceability or appearance of the finished product.

7.3.2.3.1 Corrosion Resistance

The PMV shall be constructed of materials resistant to, or suitably treated to resist, corrosion by damp air. Protective coatings that will chip, crack or peel with age shall not be used. Finish shall be color number , in accordance with FED-STD-595.

7.3.2.3.2 Toxic Materials

Materials capable of producing dangerous gases or other harmful toxic affects under conditions of high ambient temperature, including fire, shall not be used. The use of teflon covered wire, however, shall be allowed.

7.3.2.3.3 Fungus Resistance

Materials resistant to fungus growth shall be used to the maximum extent possible. All other materials shall be treated to resist the growth of fungi. The fungicidal agent shall be applied only where needed, to eliminate the treating of areas not required to be treated. The fungicidal agent shall be non-toxic to personnel handling the equipment.

7.3.2.3.4 Flammable Materials

Materials which will ignite or explode from an electric spark, flame, or heating, and which, if so ignited, will independently support combustion, shall not be used.

7.3.2.3.5 Dissimilar Metals

Unless protected against electrolytic corrosion, dissimilar metals shall not be used in intimate contact with each other.

7.3.3 Design & Construction

The supplier shall provide equipment that has been designed and constructed in a manner entirely suitable for the purpose intended.

7.3.3.1 Environmental Conditions

The PMV shall meet the requirements specified herein when subjected to each or any combination of the following environmental conditions.

Two (2) levels of environmental performance are involved:

Level 1 - The PMV shall comply with this specification when operating at Level 1.

Level 2 - This is a non-operating environment that requires equipment survival and allows for maintainence adjustments before using the PMV but does not allow replacing of parts.

7.3.3.1.1 Temperature --Ambient Air:

Level 1	+50°F to +90°F
Level 2	-65°F to +160°F

7.3.3.1.2 Humidity

For the range of temperatures specified in 3.3.1.1, the relative humidity ranges are:

Level 1	40 to 90%
Level 2	10 to 100%

The PMV shall satisfy the conditions for Level 2 including frost and condensation in and on the equipment.

7.3.3.2 Power

The PMV shall be designed to utilize 60 Hz power provided in "WYE" connection, four wire format with 115 volts between neutral and any phase. Power consumption shall not exceed 6,000 watts total, for any mode of operation.

7.3.3.3 Power and Circuit Grounding

The chassis ground and cabinet ground shall be isolated from the circuit, shield and power supply ground returns except at one point in the PMV. At this single point all grounds shall be connected together with low impedance grounding links or cables.

7.3.3.4 Cooling

The PMV shall be air cooled for heat removal and shall contain all necessary provisions for moving the air. The equipment shall be designed to minimize the generation of heat and shall not degrade the performance of the optical projection systems. Heat removal through the use of mechanical heat sinks and conduction through the unit for dissipation by radiation, shall be considered in the equipment design to minimize the capacity of the forced air cooling requirement. Intakes for cooling air shall be filtered to prevent entrance of dirt and dust particles which would degrade precision.

7.3.3.5 Size

The PMV shall conform to and function properly within the space envelope indicated on the Outline and Installation Drawing of paragraph 7.2.2. If the PMV design cannot comply with this goal approval of the NASA/MSC technical monitor shall be obtained prior to the design freeze.

7.3.3.6 Weight

The total PMV weight shall be a minimum consistent with good design and shall not exceed the weight specified on the Outline and Installation Drawing.

7.3.3.7 Modularity

The PMV shall consist of functional modular sub-systems capable of easy assembly to form the final integrated viewer assembly. Each modular sub-system shall be capable of having its requirements evaluated outside the final instrument assembly.

7.3.3.8 Human Factors

The PMV shall be designed to provide the maximum capability for efficiency of the operating and maintenance personnel. The design of the integrated display and control module shall emphasize ease of viewing with convenient location of the controls so that easy flexibility is provided, relative to manipulating the various parameters of hue, brightness and saturation, for achieving the full capability of color presentations from multiband photography, and for easy rapid registration of the four images. A full-scale mockup of the display and control module shall be prepared after the design definition phase. This mockup design must be approved by the NASA/MSC technical monitor prior to proceeding with the detail design. In general, the PMV shall be designed to meet the following conditions.

a. The PMV shall be entirely suitable for use in normal and subdued ambient artificial room light. The ambient light range for the display and control area will be from 10 to 40 foot candles.

b. The type and location of controls and adjustments shall provide reliable operation for prolonged time periods with a minimum of operator fatigue. The type and location of controls shall have prior approval by the NASA technical monitor.

c. Operation, maintenance and safety instruction plates, film loading and threading diagrams, schematic diagrams and any special alignment procedures and techniques shall be provided in appropriate locations.

7.3.3.9 <u>Reliability</u>

The PMV shall be designed to provide the required performance for 500 hours, mean-time-between failures(MTBF), with no maintenance other than lamp replacement. With routine maintenance, the equipment shall provide the required performance without degradation for 6000 hours. The service life shall be 10 years with routine maintenance and replacement of parts.

7.3.3.10 <u>Maintainability</u>

The mean-time-to-repair (MTTR) for the PMV shall not be more than 30 minutes. The maintainability provisions shall include:

a. <u>Test Points</u>

Proper quantity at significant points, compatibility with normal test probes, ease of accessiblity.

b. <u>Marking</u>

Component identification, circuit card locations, power and ground wires, cables, test points, terminal strips, terminal lugs, connectors, etc.

c. <u>Indicators</u>

Fault lights, status lights of important circuit conditions, power status indicators, mode lights, airflow, thermal conditions, etc.

d. <u>Tools</u>

The need for unique test tools or test equipment shall be minimized; standard test equipment and personnel tools shall be utilized.

e. Operational Testing

The PMV shall be designed to include access panels, sufficient cable length and cooling, as required, to allow maintenance personnel access to the test points while the equipment is operating.

f. Modular Provisions

The PMV shall be organized as an assembly of functional modules each of which is designed to allow ease of operator maintenance before and after assembly and integration into the PMV. Simplification and miniaturization is desirable and maximum standardization of components shall be employed in the design of the equipment.

7.3.3.11 Audio Noise

The noise emitted from the equipment shall not exceed 50db at a distance of three feet from any external surface of the PMV. 0 decibels is defined as 10^{-16} watts per square centimeter. Air noise from cooling devices, such as blowers or fans, shall be minimized by sizing the cross-sectional flow areas to provide relatively large flow of air at low velocity. Separate or remotely located cooling sources are not desirable.

7.3.3.12 Interchangeability

All modules and components having the same part number shall be functionally and dimensionally interchangeable. The number of different types of modules utilized shall be determined in the design definition phase with the breakdown of paragraph 7.3.2 considered as a design goal.

7.3.3.13 Dust and Moisture

Wherever practical, moving members and all other critical portions of the PMV shall be sealed to prevent entry of dust and moisture particles.

7.3.4 Design Requirements

7.3.4.1 General

The PMV shall be designed as four integrated viewers whose projected images shall be capable of being precisely superimposed on a screen for viewing or printing at various magnifications. Each of the four separate convergent optical systems shall have individual illumination systems so that the spectral quality of the light used to illuminate each of the four film rolls can be varied to obtain any color presentation desired. The illumination of each image shall be controlled by neutral density filters. The PMV shall handle four 100 foot rolls of 70mm film and provide for precise registration of any 2-1/4" square frame selected from each of the four rolls. The images shall be registered by manipulation of the X, Y, and θ controls. Each projection lens shall have fine focus capability, remotely controlled by the operator, for the various magnifications and lens adjustments to correct for differential shrinkage. The design shall emphasize human factors engineering to assure accurate and timely inputs of human engineering information into the design effort to produce an effective man-machine viewer system. Application of data and principles of human performance to all the phases of product planning, design and development of the equipment shall be utilized to maximize the performance of operator and maintenance personnel in the operation of the system. The design of the PMV shall provide for functional modular sub-systems, capable of ready assembly into the desired viewer configuration, which shall represent the current state-of-the-art. These modules shall be capable of replacement with similar but more advanced modules as the state-of-the-art, of the various technologies employed, is advanced. Appropriate working surface and writing shelves shall be provide to facilitate placement of operator textual or recording materials as shown in Drawing RG-321-D1.

7.3.4.2 Display and Control Sub-system

The integrated display and control sub-system module shall provide the capability for maximum ease of operation. A full scale mockup of this sub-system shall be prepared, as per paragraph 7.3.3.8, representative of the following specified parameters.

7.3.4.2.1 Viewing Screen

The viewing screen shall be mounted in the sub-system at an angle consistent with drawing RG-321-D1. The material shall be rigid and provide a durable surface for normal viewer use. Screen size shall be 15 inches by 15 inches with adjustable masks to reduce the usable viewing area to 6-3/4 inches by 6-3/4 inches. These masks shall have separate X and Y adjustments so that auxiliary data, such as density step wedges, can be simultaneously displayed. The viewing screen material shall be the result of careful study and testing of various rear projection screen materials. The viewing screen selected shall provide the best combination of image quality and brightness over the spectral bandwidth specified. Contrast retention, freedom from color and capability of viewing by more than one individual shall be inherent requirements.

The viewing screen shall be mounted so that it is properly isolated from any shocks or vibrations which would be detrimental while having provision for easy replacement. The viewing screen shall be mounted on slides so that it is capable of easy transfer out of the projection display area for either viewing the aerial image with the binocular microscope or for recording the desired image with the image recording system module.* A 4 X(nominal) wide field magnifier shall be provided over the viewing screen to aid in registration and for viewing high resolution detail.

7.3.4.2.2 Controls

The following controls, described in more detail in subsequent paragraphs, shall be provided:

7.3.4.2.2.1 Internal Controls

-End of Film Switches

Illuminates indicator in display area when end of each film roll is approaching and automatically stops film drive. Operator actuates manual over-ride when he wants to wind or rewind the entire film roll.

-Platen Up/Down Switches

Informs film transports that the platen is up and that film can now be safely transported. Illuminates indicator near film drive controls and automatically interlocks all four film drives for ganged operation.

-Thermostats

Keeps cooling air flow after lamp shut-off

* (see Section 7.3.4.8)

-Interlocks

As required for safety

7.3.4.2.2.2 External Controls

The following controls, as indicated in Drawing RG-321-D1, shall be provided:

-Power Status

-Magnification Selector

-Fine Focus (4)

-Film Transport Master Speed Control & Individual On/Off Switches (4)

-Film Footage Counters (4)

-Image Rotation (4)

-Registration in X (4)

-Registration in Y (4)

-Registration Speed Changer (4)

-Saturation Lamp Power (4)

-Saturation Lamp Dimming (4)

-Color Lamp Power (4)

-Color Lamp Dimming (4)

-Filter Selector (4)

7.3.4.2.3 High Magnification Viewing

The display and control sub-system shall incorporate a high magnification viewing capability for viewing a portion of the projected magnified aerial image. This high magnification viewing sub-system shall provide continuously variable, wide field, viewing optics having the capability of extending the discrete projected magnification by a factor of 4 to 1. The zoom viewing optics shall be provided with appropriate support structure and sliding means, integrated with the viewing screen support structure, for easy access to the aerial image of the discrete magnification projection system. The magnification range shall be from 2X to 8X, parfocal, with a fine focus over-ride to accommodate variations between operators. The screen image shall be nominally 7 inches divided by the magnification of the zoom system and the binocular eyepieces shall be adjustable to suit the needs of all size operators in accordance with existing commercial practice. No color fringing shall occur when changing magnification. The mounting arrangement shall be in accordance with drawing RG-321-D1 and shall emphasize ease of usage and human factors criteria. The resolution capability of the zoom optics shall be 6 lines per millimeter per power.

7.3.4.3 Illumination and Filtering Sub-system

Each of the four illumination and filtering sub-systems shall be identical in performance and design with standardized parts and components used to the highest degree. Each light source shall operate at a color temperature of 3200°K and shall be capable of producing an image with high enough intensity and even brightness to be suitable for study and evaluation in a normally lighted room. The intensity at the viewing screen, without film (open gate), shall be at least 600 foot-lamberts for each individual illumination system on axis and at the maximum enlargement. The uniformity of illumination shall be ± 10%, including the corners. Each of the four illumination sub-systems shall be capable of varying the hue, saturation and intensity will be independently variable from 10 to 100% by use of neutral density filters. The illumination shall be free from irregularities and local differences in intensities across the viewing screen. The filters shall be mounted in an appropriate place in each of the four optical projection paths. Provision shall be provided for easy interchange of the filters of each sub-system for displaying the full complement of composite color images. Each of the four illumination and filtering sub-systems shall have provision for at least three (3) filters and an open aperture. One of these filters shall have a dominent wavelength of 615nm ± 2nm and nominal chromaticity coordinates of (.68 ± .01, .31 ± .01) when measured with an illuminant "C" source. This filter shall have a nominal bandpass of 120 ± 5nm and a peak transmission of 90% ± 1%. The second filter shall have a dominant wavelength of 470nm ± 5nm and nominal chromaticity coordinate of (.141 ± .01, .080 ± .01) when measured with an illuminant "C" source. This filter shall have a nominal bandpass of 140nm ± 5nm and a peak transmission of not less than 65%. The third filter shall have a dominent wavelength of 540nm ± 2nm and nominal chromaticity coordinates of (.255 ± .01, .690 ± .01) when measured with an illuminant "C" source. This filter shall have a nominal bandpass of 130nm ± 5nm and a peak transmission of not less than 55%.

7.3.4.4 <u>Film Transport Sub-system</u>

The film transport sub-systems shall provide the means for moving each film roll in either direction along its length in precise alignment with the film gate. All surfaces contacting the film shall be polished to prevent damage to the film. Film flattening for each film roll shall be provided by optically flat glass plates which uniformly transmit wavelengths from 4000°A to 9000°A and which are automatically released just prior to film transport. The releasing mechanism design shall be integrated with a time delay in film transport so that the minimum time delay without damaging film, is obtained. Proper alignment shall be provided by film guides, one of which sall be lightly springloaded to bank the film against a fixed and stable reference plane. Film loading and threading through the projection gate shall be accomplished in less than one minute for each roll of film. Provision shall be provided for accommodating cut film of 70mm width and sufficient length to permit easy handling. Each film transport shall be capable of moving the film smoothly and evenly so that it is snugly wound onto the spools in such a manner as to preclude marks, creases, abrasions, tears or other physical damage to the film. Each film transport shall have reversible variable speed drive capabilities from 0.1 feet/minute to 100 feet/minute. Film footage counters or indicators shall be provided which are capable of manual reset. The counters shall have a resolution, or least count, of 0.1 feet and shall not have an accumulative error greater than 0.13 feet at the end of 100 feet of film travel.

7.3.4.5 Precision Registration Sub-system

The PMV shall have a registration capability of one-half of a resolution element (5microns at 100 lines/millimeter) as evidenced by the projection and superimposition of four separate resolution target arrays covering the 2 1/4 inch square format. Four identical resolution traget arrays, each containing nine (9) resolution targets, are considered adequate for testing field flatness and resolution as well as registration. Each of the four projection sub-systems shall be tested with the targets in place and illuminated with the three primary colors using the filters previously specified. Registration shall be effectively accomplished by primarily providing precise and repeatable micro-metric adjustments of each film frame flattened in its film gate for X,Y and θ. Each individual

X and Y adjustment mechanism shall have a resolution capability (being able to affect as small a displacement) of 1 micron over a total range of 2 millimeters. Backlash of each adjustment mechanism shall be eliminated by usage of spring-loaded, wear compensating mechanisms and, in any event, shall not be greater than 1 micron. The total range of 2 millimeters travel shall be capable of being covered in not more than 20 seconds of time. These precision linear adjustments of the film frame relative to the optical axis shall be independent of film transport (X) and lateral film positioning (Y) provisions. The rotation (θ) mechanism shall be independent of, and not be affected by, the X and Y adjustment mechanisms. It shall be capable of rotation through an angle of ± 3° in not more than 20 seconds of time and shall have a resolution capability of 5 seconds of arc. Film flattening, which is integrated with the film transport sub-system, shall not affect or disturb the registration adjustment mechanisms.

7.3.4.6 Projection Optics Sub-system

The projection optics sub-system shall provide magnifications of 3 X and 6X for each of the four 2-1/4 inch square images. These fixed discrete projection magnifications, when used in conjunction with the 4 to 1 zoom binocular microscope of the display sub-system, shall provide a total magnification capability of 3X through 24X. Each projection lens shall have its chromatic aberrations tested, with each of the filters to be used, so that their focal length change versus wavelength shall not exceed ± 0.1 per cent. The short conjugate distortions of each lens (radial and tangential) shall not be greater than ± 5 microns throughout the field. The focal length and angular coverage shall be such that each lens shall have a minimum acceptable resolution of 100 lines per millimeter at the maximum off-axis angle. The curvature of field shall be such that the preceding resolution shall be the minimum obtained, referred to the film gate. Each projection lens shall be mounted in precisely controlled mechanisms so that very fine adjustments can be made in fine focussing. The fine focussing (Z) resolution capability shall be 0.5 microns over a range of 0.5 millimeters. The angular coverage shall be extended beyond the 2-1/4 inch square image coverage for displaying auxiliary imagery such as step wedges, fiducials, etc., for which the previously specified performance parameters are not required. The exact magnification ratios employed shall be calibrated and specified to 0.1 per cent on the magnification changing control. All lens elements shall be mounted in accordance with best practices, Each lens barrel or cell shall be permanently and legibly marked with the exact focal length of the lens it contains to the nearest micron. All exposed first surface mirrors shall be protected by a coating which shall provide maximum reflectivity over the wavelengths specified. The flatness shall be as required to meet the overall specified resolution requirement and shall be of sufficient thickness, relative to the size, so that no degradation in performance will occur with respect to time and realignment adjustments. Means shall be provided for optical alignment of complete assemblies after replacement.

7.3.4.7 Cooling Sub-system

The illumination and filtering sub-system housing shall be properly ventilated to transfer heat from this module. The cooling sub-system inlets and outlets shall not produce light leaks which may introduce stray light into the viewing screen. Shielding shall be provided to keep unwanted light from the screen. The cooling blowers and motors shall not produce detrimental vibrations and shall be appropriately isolated from the main structural support. Interlock circuits shall be incorporated in the PMV to prohibit operation of the projection lamps unless the cooling system is in operation. The temperature rise at any film gate shall not exceed 25°F above an ambient temperature of 90°F when the PMV is operated continuously at maximum brightness for 4 hours with uniformly exposed films having a density of 1.6, clamped at each film gate. If the cooling system module is designed with the blower unit as an auxiliary, remotely located package, it shall be provided with casters and appropriate flexible ducting to permit its usage in a 6 foot radius around the PMV. Thermostatic control shall be provided in each lamp housing so that blower or fan operation is continued, after the lamp is turned off, so that residual heat in the lamp housings will be dissipated.

7.3.4.8 Image Recording Sub-system

The image recording sub-system module shall be integrated into the display and control system module so as to utilize the same precision slide rails of the projection screen. When positioned into the optical path, the recording emulsion surface shall occupy the exact same plane previously occupied by the diffuse coating of the projection screen so that the superimposed imagery shall be recorded with minimum loss of detail. The maximum allowable degradation of resolution shall be 10 per cont. Capability for both roll and sheet film shall be provided. The image recording sub-system shall incorporate a light-tight film magazine or cassette having film transport and film flattening capabilities which shall be as simple as possible, consistent with the specified requirements. Film width shall be 9 1/2 inches wide and capability for 100 feet of roll film shall be provided. 8 x 10 cut film can also be used at the expense of clipping one edge of the basic square format. Precision vertical slide rails shall be provided to permit covering any 9 1/2 inch portion of the viewing area with the image recording module. When using roll film, the film transport, film flattening and exposing shall all be automatically accomplished. A film cutter shall be built into the exposed film spool holder so that any desired amount of the exposed film can be removed and processed without exposing and processing the entire film supply. When using cut or sheet film holders, the exposure shall be manually implemented. Exposure shall be controlled by a timer with the time setting determined by photometer readings of the specific areas of interest. The general configuration shall be compatible with the form outlined in drawing RG-321-D1.

7.3.4.9 Structural Support Sub-system

The structural support sub-system shall provide a light tight housing for the illumination and projection modules as well as structural support for all the previously specified sub-systems. Hinged access doors or removable panels shall be provided for easy access for maintenance purposes. The PMV's exterior shall be free from protruding parts or sharp edges which may cause injury to operating personnel or which may be damaged during operation or shipment. The structural support shall be fabricated of metal which shall be completely annealed and free of internal stresses so that the precise alignments obtained will not be affected by relaxation of load carrying elements. The structural design shall emphasize the criteria of stiffness and minimum deflection or elongation rather than stress. The structural support shall be provided with appropriate rubber tired casters for portability and with leveling jacks for installation. Shock mounts with relatively high damping shall be attached between the jacks and the support structure. The precision registration and projection optics sub-systems shall be interfaced on to their individual structural support which shall be secured to the main structural support with relatively soft vibration isolators. Light baffling between the projection system support and the main support structure shall be accomplished through the use of flexible non-vibration conducting plastic foam material. The housing or enclosure shall be painted dull black on the inside to reduce internal light reflections.

7.4. QUALITY ASSURANCE PROVISIONS

7.4.1 Responsibility for Inspection

Unless otherwise specified in the contract or purchase order, the contractor shall be responsible for the performance of all Quality Assurance provisions as specified herein. Unless otherwise specified, the contractor may utilize his own facilities or any commercial laboratory acceptable to NASA to conduct the tests.

7.4.2 Mechanical and Electrical Inspections

The PMV shall be carefully examined to determine compliance with the requirements of this specification which are not covered by specific test procedures. This includes quality of workmanship, grounding, maximum weight, power consumption, use of proper materials and finishes, visible defects, or any other imperfections that would result in rejection of units. All moving parts and controls shall be visually examined to assure that they operate freely without sticking or binding, that they are easily identified and that no control element can be inadvertently actuated. The PMV shall be examined for adequate operation, maintenance and safety instruction plates, film loading and threading diagrams, special instructions and conformance to the maintainability requirement of paragraph 7.3.3.10.

7.4.3 Acceptance Tests

Acceptance tests shall be accomplished in accordance with the approved test plan. The NASA technical monitor shall be advised at least two weeks prior to starting the tests so that a representative may be designated to witness or supervise the tests when so desired. The acceptance tests shall be classified as those tests required to determine compliance with the specified performance requirements. The Contractor shall furnish all equipment and shall be responsible for accomplishing the acceptance tests. All inspection and testing shall be subject to approval and surveillance by the NASA. The PMV shall be operated long enough to permit the equipment temperature to stabilize.

7.4.4 Test Plan

The test plan shall be prepared and submitted to NASA sixty days prior to starting the tests. The test plan shall include but not be limited to the following tests:

7.4.4.1 Registration/Resolution Test

The PMV shall be subjected to a registration/resolution test at the 3X and the 6X magnifications to verify compliance in attaining the requirment of 100 lines per millimeter resolution for the super-imposed image. The 4X wide field magnifier or the 2X to 8X zoom binocular microscope shall be used for aided reading of the resolution targets. The identical resolution target array, at each projection gate, shall consist of nine (9) standard USAF targets having at least 128 lines per millimeter targets.

7.4.4.2 Illumination Test

Each illumination sub-system of the PMV shall be tested for conformance to the open gate brightness requirement of 600 foot-lamberts and for compliance to the requirement for uniformity of illumination of ± 10 per cent.

7.4.4.3 Temperature Rise Test

A temperature rise test shall be simultaneously performed on all four illumination sub-systems to determine compliance with the requirement of 25°F maximum temperature rise at the film gate, at the maximum brightness, with films having uniformly exposed densities of 1.6, for a period of four (4) hours.

7.4.4.4 Audio Noise Test

An audio noise test shall be performed simultaneously with the temperature rise test to verify conformance with the requirement of 50 db maximum at 3 feet from any external surface of the PMV.

7.4.4.5 Reliability/Maintainability Tests

The PMV shall be operated a minimum of 100 hours prior to conducting the acceptance tests. The essential data and characteristics of the various sub-systems shall be recorded during this pre-acceptance test phase to assure satisfactory equipment operation in accordance with the requirements of Section 7.3 of this specification. A maintainability demonstration shall be performed to verify conformance with the MTTR requirement of 30 minutes.

7.5. PREPARATION FOR DELIVERY

7.5.1 General

The PMV shall be preserved, packaged, packed and marked for the level of shipment specified in the contract or the purchase order.

7.5.2 Openings

Metal caps or plugs shall be used to cover all openings and to prevent dirt, dust, or metal particles from entering the PMV.

7.5.3 Marking

Each package shall be durably and legibly addressed, as specified in the purchase order. Markings shall not be damaged when the packages are opened.

7.6. NOTES

7.6.1 Engineering Data

The requirements for engineering data will be specified on the

Invitation to Bid and/or the Purchase Order.

7.6.2 Design Analysis Report

The contractor shall prepare and submit to NASA a design analysis report upon completion of the design definition phase, within 60 days from the date of contract award. Approval of this report by the NASA technical monitor shall constitute the design freeze. Included with the design analysis report shall be a full scale mockup of the display and control sub-system module. All design details that will be utilized in the fabrication of the PMV shall be itemized. Conclusions for the design definition shall be thoroughly substantiated.

7.6.3 Precedence of Documents

When the requirments of the contract, this specification, or applicable subsidiary specifications are in conflict, the following precedence shall apply:

7.6.3.1 Contract

The contract shall have precedence over any specification.

7.6.3.2 This Specification

This specification shall have precedence over all applicable subsidiary specifications. Any deviation from this specification, or from subsidiary specifications where applicable, shall be specifically approved in writing by NASA.

7.6.3.3 Drawings

The drawing(s) referenced in paragraph 7.2.2 have precedence over referenced specifications.

7.6.3.4 Referenced Specifications

Any referenced specification shall have precedence over all applicable subsidiary specifications referenced therein. All referenced specifications shall apply to the extent specified.

7.6.4 Performance Objectives

Simplicity of operation, ease of maintenance and an improvement in the performance and reliability of the specific functions beyond the requirements of this specification, shall be considered in the fabrication of the PMV. Where it appears a substantial improvement in simplicity of design, performance, ease of maintenance or reliability will result from the use of materials, parts and processes other than those specified in this specification, it is desired that their use be investigated. When investigation shows advantages can be realized, a request for approval shall be submitted to NASA for consideration. Each request shall be supported by complete supporting information.

7.6.5 Program Plan

The contractor shall prepare and submit to NASA a program plan delineating the major tasks required to fulfill the specified requirements of the PMV and the manner in which these tasks will be achieved. The plan shall present a series of work phases, the planned activities for each work phase as specific detailed tasks and the results expected from each task. The plan will utilize work schedules, graphs, flow diagrams and other similar means to reduce the amount of verbal descriptive material.

7.6.5.1 Subcontract Plan

As part of the program plan, the contractor shall prepare a subcontract plan which includes the method of procurement, procurement schedules and procedures by which control will be exercised over the subcontract effort.

7.6.6 Final Report

The final report shall be submitted one month after delivery of the PMV. The final report shall incorporate all status reports and shall report all the technical efforts and achievements accomplished and any future recommendations.

SECTION 8

ACCEPTANCE TEST & CALIBRATION SPECIFICATION, RG 321-ATS FOR PMV

8.1 SCOPE

8.1.1 Scope

This specification describes the acceptance test and calibration requirements for a Precision Multiband Viewer, hereinafter referred to as PMV. The PMV is to be used for the screening and precision analysis of multiband photographic imagery obtained with multiband photographic systems to be used by the NASA. The test program shall be designed to provide only the minimum tests necessary and duplication of efforts shall be prevented. The contractor shall furnish all equipment and test material and shall be responsible for accomplishing the acceptance tests. All inspection and testing shall be subject to the approval of the NASA or its duly authorized representative.

8.1.2 Place of Performance, Inspection & Acceptance

The primary place of performance for acceptance of the PMV will be the contractor's facility or any commercial laboratory acceptable to NASA. Final inspection and acceptance of documentation, such as technical reports and program plans, shall be accomplished at NASA by the contracting officer or his representative.

8.1.3 Acceptance Test Procedure & Test Plan

The acceptance test procedures and test plan shall be prepared and submitted to NASA for approval, sixty days prior to starting the tests, based upon this specification and Preliminary Specification RG-321-S, Precision Multiband Viewer (2 December 1969). Data sheets shall be prepared to record the results of acceptance testing for the performance requirements specified. Acceptance testing shall be accomplished in accordance with the following general requirements:

8.1.3.1 Environmental Conditions

Acceptance testing shall include environmental exposures, or combinations of environmental conditions of temperature and humidity, as operating conditions for the following levels:

8.1.3.1.1 Temperature of Ambient Air: +50° to +90°F

8.1.3.1.2 Humidity: 40 to 90% R.H.

8.1.3.2 Calibration & Alignment

The PMV shall have been calibrated and aligned prior to conducting the Acceptance Tests.

8.1.3.3 Operational Capability

All possible normal and abnormal operational modes, procedures, and functions shall be applied to verify "fool-proofness" of design and that appropriate interlocks are provided.

8.1.3.4 Test Failures

Acceptance Tests shall be performed under strict control of the detailed Test Procedures, which shall be approved by the NASA or its duly authorized representative. Adjustment or manipulation of any PMV controls or hardware is not permitted during acceptance testing unless it is normal to in-service operation. When a failure occurs, it shall be reported with all pertinent data such as part name and number, specific test being conducted when failure occurred, conditions at time of failure, description of failure and cause of failure. The degree of retest necessary in event of failure shall be proposed and submitted for approval and shall be approved by the NASA or duly authorized test representative. A failure is defined as the inability of the PMV to perform any of its required functions within the specified limits of the Acceptance Test Procedures.

8.1.3.5 Repairs & Modifications

Any repairs, modifications or replacements after completion of the Acceptance Tests shall require retesting to assure the acceptability of the change. The degree of retest necessary shall be proposed and submitted for approval.

8.1.4 Test Subject Training & Test Material

The test subject shall be experienced & shall have had sufficient training so that evaluation of the PMV's effectiveness in terms of speed, accuracy, completeness or correctness, as defined for these tests, shall be obtained. Sufficient training time shall be provided so that the test subject shall have been familiarized with the PMV's controls and operation, the test objectives, routines and test material. The test material shall be defined and recommended by the contractor and shall be approved by the NASA, or duly authorized representative, 90 days prior to conduct of the tests. It shall include, but not be limited to a distortion grid and resolution target array covering the 2 1/4" x 2 1/4" format and multiband images obtained by various camera systems, the characteristics of which will be supplied by the NASA.

8.2 PRE-TEST PROVISIONS

8.2.1 Examination & Inspections

Each module of the PMV shall be examined carefully to determine accuracy of dimensions, that the material and workmanship requirements have been met and that no visible defects, or any other imperfections, exist which would result in rejection. The extent of the mechanical and electrical inspections shall be defined in the detailed ATP in accordance with the PMV design and shall consist of at least, the following:

A. Quality of workmanship

B. Grounding of electrical sub-assemblies and modules

C. Maximum weight check

D. Maximum power consumption

E. Appropriateness of materials and finishes

F. Corrosion protection

G. Operation of moving parts and controls

H. Proper identification of controls and parts

I. Nameplates and special instructions

J. Safety precautions

K. Operation and maintenance features

L. Film loading and threading diagrams

8.2.2 Operating Time

The PMV shall be operated a minimum of 60 hours prior to conducting the acceptance test. This pre-test operational period shall have included regular operation and manipulation of all controls and functions.

8.2.3 Operational Tests

Prior to conducting any of the operational acceptance tests, as specified in Section 8.3, the PMV shall be operated long enough to permit the equipment temperature to stabilize and to check the operation of all essential functions. A check-list shall be prepared as part of the ATP to verify these operations and eliminate the need for retesting due to any omissions or irregularities.

8.2.4 Filter Wavelength and Transmission Calibration

The filters shall be tested and calibrated prior to conducting the operational acceptance tests to verify that their dominant wavelengths, nominal chromaticity coordinates, nominal bandpass and peak transmissions are in accordance with the specified parameters of each band. The test and calibration shall be recorded on data sheets prepared as part of the ATP.

8.2.5 Projection Lens Calibration

The preliminary calibration data, used for selecting and matching the four lenses of the PMV, shall be verified by calibration tests of each of the four lenses as installed in the PMV. These calibrations shall be performed with a precisely calibrated master grid having a 2 1/4" X 2 1/4" format, at each of the projection magnifications. The zoom microscope of the PMV may be used for measurements, or an external microscope with reticle or filar eyepiece, etc., may be used. Data sheets shall be provided which can record the specific measurement of each grid point from its nominal position and the direction sign.

8.2.6 Measuring and Test Equipment Calibration

All measuring and test equipment shall be inspected prior to usage to assure that they are in proper working order and that they have had their accuracy and performance verified by the Contractor's Quality Control or Calibration Department. The test instruments used, and their last calibration date, shall be recorded on the appropriate data sheet for each test.

8.3 Test Objectives and Performance Criteria

8.3.1 Test Objectives

The acceptance testing shall be performed in accordance with the approved ATP. The NASA technical monitor shall be advised at least two weeks prior to starting the tests so that a representative may be designated to witness or supervise the tests.

8.3.2 Performance Criteria

The acceptance tests shall include but not be limited to the following tests for compliance with the specified requirements of Specification RG -321-S:

8.3.2.1 Film Transport and Film Footage Counting

8.3.2.2 Illumination Brightness, Uniformity and Filtering

8.3.2.3 Displays and Controls

8.3.2.4 Registration and Resolution

8.3.2.5 Image Recording

8.3.2.6 Temperature Rise

8.3.2.7 Audio Noise

8.3.2.8 Reliability and Maintainability

8.4 Test Implementation Plan

A detailed test implementation plan and schedule shall be prepared delineating the sequence of acceptance testing with realistic start and completion dates. Significant milestones shall be highlighted in this plan and the necessary test equipment and material required for each test shall be indicated. The sequence of tests to be performed does not necessarily have to follow that of paragraph 8.3.2, but should have some specific rationale and logic for most effective implementation of the PMV's acceptance testing.

8.5 Evaluation of Test Results

The test record data sheets shall be organized and fashioned so that all the test data is easily analyzed and reviewed for simple evaluation of the necessary objectives. Each test result shall be isolated from the other test data to minimize confusion and permit repeating any specific test without revising the entire test record data sheets. Where different test data is observed or read by different testers, the test data shall be averaged after each tester has taken multiple readings and averaged his own observations. Any discrepancies in test data shall be justified to the NASA test representative or the particular test in question shall be repeated.

9.1 PRE-REGISTRATION OF FILMS FOR USE IN MULTISPECTRAL VIEWERS

9.1.1. INTRODUCTION

Multispectral photography uses sets of spatially identical photographs, each taken through a different optical filter and containing different spectral information. To combine a set of multispectral films into a color display, it is essential that the component images be superposed in precise register. Provision for registering the images can be incorporated in the configuration of a multispectral camera, in the design of a multispectral viewer, or in various processing steps which take place between photography and viewing.

In the discussions which follow, a number of alternative approaches to registration are examined, and the advantages of pre-registration techniques are developed in detail. Practical, straightforward pre-registration methods are described.

9.1.2. REGISTRATION PROCEDURES

The three basic ways in which multispectral films can be registered are as follows:

A. Implicit Register In The Multispectral Camera Design

A multilens camera is designed so that each set of multispectral images is exposed in "unitary" form, combining on one sheet of film, all of the images which comprise the set, in a fixed geometrical arrangement. By using this same spatial arrangement in a viewer, the unitary sheet positives can be registered for projection with minimal effort.

B. Registration In Printing

In a system which uses a cluster of separate cameras, rather than one integrated multispectral camera, the separate negatives can be registered mechanically, before positives are printed for viewing. Mechanical register is accomplished by means of a special register punch, which punches two small precisely spaced holes along one edge of the film, outside the formate area. By means of appropriate register techniques (described in Section 4) the fixed location of the punched holes with respect to the image is maintained on all of the negatives in a given set, thus registering them with respect to one another. The pre-registered films can then be positioned for printing, on register bars, so that the holes in the film engage pairs of pins whose diameter and spacing are precisely matched to the punch.

The set of mechanically registered negatives can be printed to yield:

a. Individual positives with punched register holes, which will engage sets of precision pins on the film carrier glass of a viewer, so that the positives can be reproducibly mounted in any desired geometrical arrangement, or

b. A unitary sheet positive with any desired spacing among the component positives of the set, to fit any fixed spacing arrangement in a viewer.

C. <u>Registration In The Viewer</u>

In this method, there is no provision during exposure and processing of the films for registration or indexing of any kind. Registration is accomplished by positioning the films in the viewer and adjusting them until coincidence is accomplished.

9.1.3. COMPARISON OF REGISTRATION PROCEDURES

Only the two alternatives of pre-registration in printing, and registration in the viewer, lend themselves for consideration in the design of multispectral viewers for general use, where the available film has been exposed in clusters of separate cameras.

It is important to note that in <u>either</u> of these two registration schemes, any scale descrepancies among the individual positives must be corrected before registration can be attempted. Clearly, an attempt to superpose two images of different scale will be time consuming and unsuccessful. The sequence of obtaining approximate register and <u>then</u> correcting for scale can serve no useful purpose, since a subsequent re-registration step would obviously be required.

Pre-registration of the films, before they are viewed, offers many advantages, as discussed below. Registration in the viewer, on the other hand, has only one possible advantage to commend it: the user is equipped to handle sets of separate films and is not totally dependent on the availablity of films in special pre-registered format. As described in Section 4 however, it is a relatively simple matter to provide the user of pre-registered films with a relatively inexpensive device with which he can do his own pre-registration of loose individual films when necessary.

The principal advantages of pre-registration are as follows:

A. The registration of any given set of negatives is accomplished efficiently, <u>once and for all</u>, at a central station and any number of unitary pre-registered release positive films can be made and distributed to users, who need simply insert a unitary positive into the viewer and move it into register within a matter of seconds. This arrangement avoids the substantial total of wasted effort which would be involved if the time consuming process of registering a given set of separate films were to be repeated by <u>each and every user, each and every time he had occasion to examine a particular set.</u>

B. Pre-registration can significantly reduce the cost and complexity of viewer design and thereby help make viewers more readily available to broader classes of users. A viewer with full capability for registering four separate films requires four film stages, each with three degrees of freedom (Cartesian coordinate movements plus angular rotation) to cover a wide range of adjustments. When pre-registered films are used, even a precision viewer need only have provision for minor adjustments and a simplified, low cost viewer can function with only a rudimentary capability for adjustment.

C. With pre-registered films a reasonably large portion of the viewer occupancy time can be devoted to the desired end-use -- examination of multispectral displays -- instead of being wasted on lengthy register operations.

D. It is only with the use of pre-registered films that a viewer can provide the all-important capability for reasonably rapid frame-to-frame comparisons of multispectral displays. If a pair of displays to be compared are separated in time by the lengthy period required for registering a set of separate films, the operator's visual recollection of the first display will be seriously impaired by the time he sees the second display. Though the two displays could be compared by photographing them and examining the resultant records, this type of comparison is far less useful than its real-time, on-screen counterpart.

Pin registration can provide the 5 micron accuracy requirement if magnification is provided for the viewing and alignment operation. A minimum of 10 x magnification will suffice; however, 20 x will reduce operator judgement factors.

9.1.4. RECOMMENDED REGISTRATION TECHNIQUES

All preparation of pre-registered films for use in multispectral viewers can be accomplished through the use of only two basic techniques. These are:

A. A registration printing system for production of unitary release positives, arranged in a format to match that of the viewer.

B. A simple registration device to accompany each viewer, so that the user can pre-register sets of separate positives, in those cases where pre-registered unitary positives are not available.

The basic equipment required for both of the above techniques can be readily assembled, at modest cost from commercially available registration components, such as are widely used in graphic arts color separation work, and dye transfer printing.

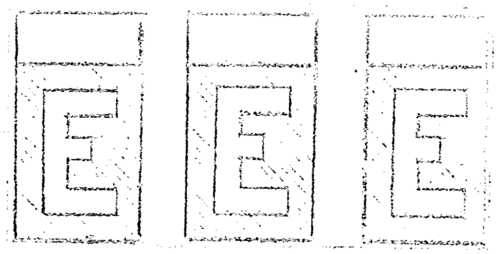
9.1.4.1 Pre-registration Printing System

The recommended system for pre-registration printing of unitary positives uses two basic equipment items: a precision register punch, and a special contact printing glass containing precision ground pins whose diameter and spacing match those of the punch.

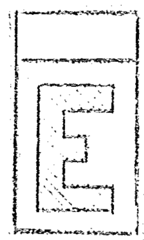
The operations of pre-registering a set of negatives and printing unitary release positives from them are shown schematically in Figure 1. (Though the figure shows a set of three positives, the technique is equally applicable to sets of four or more.)

FIGURE 1- REGISTRATION TECHNIQUE FOR PRINTING PRE-REGISTERED UNITARY POSITIVES

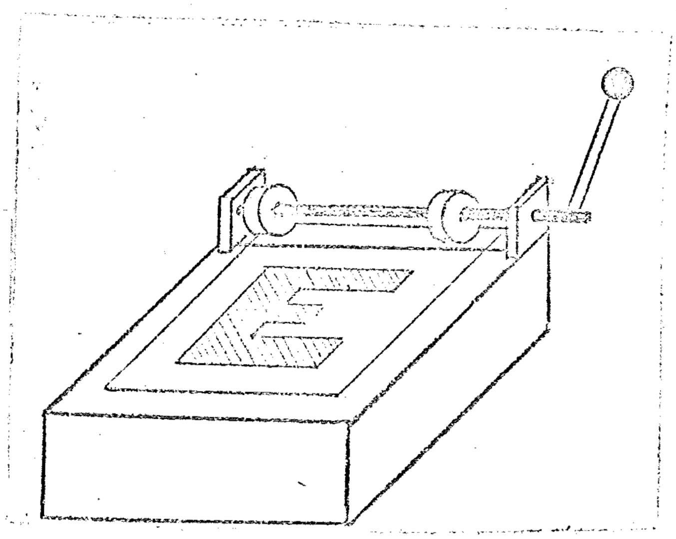
(a) START WITH 3 SEPARATE SCALE-CORRECTED NEGATIVES



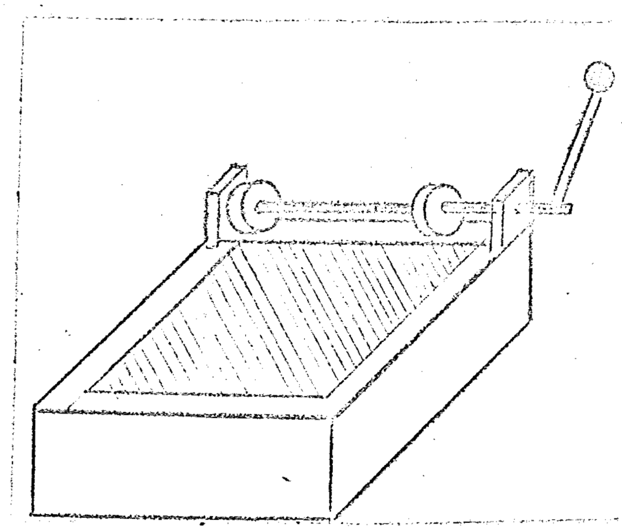
(b) MAKE ONE REGISTRATION GUIDE POSITIVE



(c) REGISTER THE NEGATIVES



Register Punch Mounted on Light Table, with Register Guide Positive Securely Positioned



Typical Negative, Shown In Register with The Register Guide Positive

(d) REGISTERED SET OF NEGATIVES

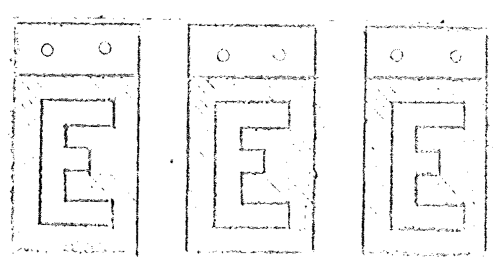
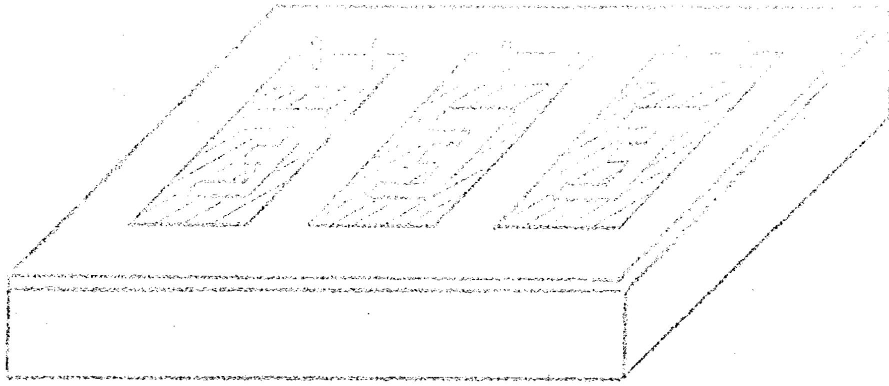
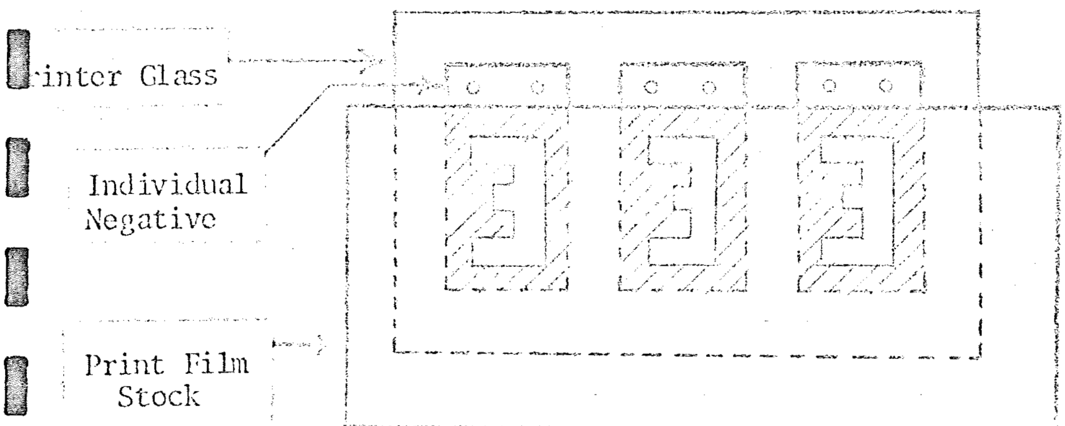


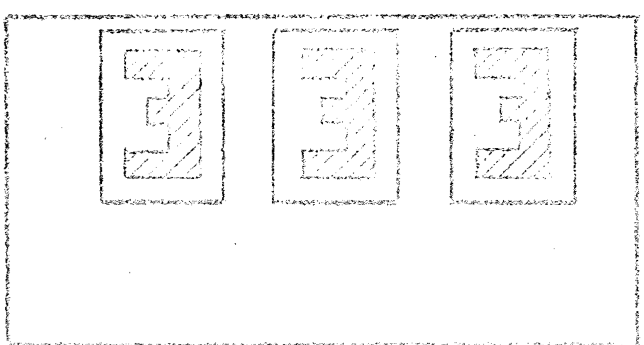
FIGURE 1 (CONTINUED)

(e) MOUNT REGISTERED NEGATIVES ON SPECIAL PRINTER GLASS (Punched holes in films engage precision pins cemented to glass.)





(f) PRINT UNITARY POSITIVES FOR RELEASE TO USERS



Unitary Positive, Consisting of 3 Images In Fixed Geometric Arrangement

Starting with a set of three separate negatives (see Figure 1a) a Register Guide Positive transparency (Figure 1b) is printed from any one of the negatives.

Using a precision register punch mounted on a light table (as shown in Figure 1c) the Register Guide Positive is positioned on the light table and secured in place. Each negative of the set, in turn, is registered to the Register Guide Positive, and register holes are punched along one side. The use of negative and positive in this fashion provides a critical, visual indication of register: when the images coincide, all brightness differences appear smoothly cancelled, without fringing. A low power microscope, not shown in the illustration, can be used to aid in registration.

The resulting set of registered negatives is depicted in Figure 1d. For printing of unitary positives, these negatives are mounted on a special pin register printing glass in which are embedded three pair of register pins. (See Figure 1e.) Each pair of pins matches the hole diameter and the spacing between holes produced by the punch. The spacing among the three pairs of pins (i.e., the spacing among the three films of the set) is arranged to match the viewer format.

The final unitary positive is shown in Figure 1f. No register holes are necessary in unitary positives of this type, since the fixed geometrical relationship among the three images is sufficient to provide rapid register in the viewer.

The required type of pin register printer glass can be readily obtained from commercial sources and can be used with any type of flat-bed contact printer. It is important to note that, by using different pin register printing glasses, each with a different spacing among the three films, a given set of negatives can be used for printing unitary positives matched to any number of different viewer format configurations. In other words, the use of pre-registered films does not freeze the viewer format design in any way.

9.1.4.2 User Technique For Registration Of Separate Positives

In the interim period before pre-registered unitary positives will have become widely available, users will be readily able to register existing sets of separate positives, using a technique very similar to that employed for registration printing. After pre-registered positives have come into general use, provision for user registration will still be needed for occasional sets of separate positives.

As shown in Figure 2, the recommended technique for user registration starts with a set of three separate positives (Figure 2a) from which a Register Guide Negative is made (Figure 2b).

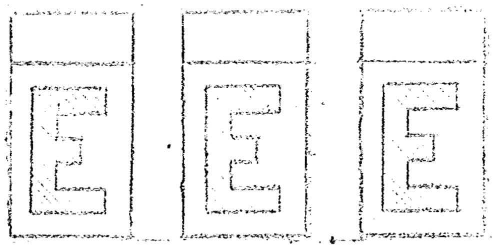
The procedure for obtaining register (indicated in Figure 2c) is identical with that used in the printing system described previously.

The set of punch-registered positives (Figure 2d) is mounted on a viewer carrier glass, which is provided with register pins, properly spaced to the viewer format. (See Figure 3e.)

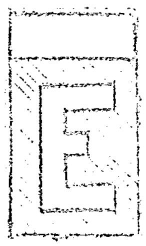
To implement the use of this method, each viewer designed for use with pre-registered films would be provided with the following accessories: a register punch, and two or more pin register glass carriers. (Having more than one carrier available would facilitate rapid frame-to-frame comparison.)

FIGURE 2 - USER TECHNIQUE FOR REGISTRATION OF SEPARATE POSITIVES

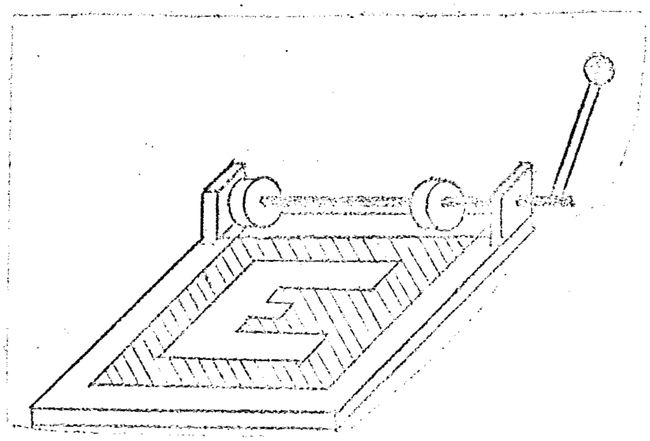
(a) START WITH 3 SEPARATE SCALE CORRECTED POSITIVES



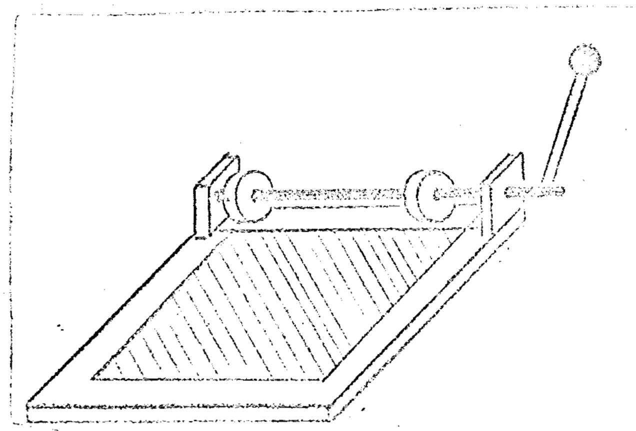
(b) MAKE ONE REGISTER GUIDE NEGATIVE



(c) REGISTER THE POSITIVES



Register Punch with Transparent Baseplate, Showing Register Guide Negative Mounted in Place



Typical Positive, Shown in Register with the Register Guide Negative

(d) REGISTERED SET OF POSITIVES

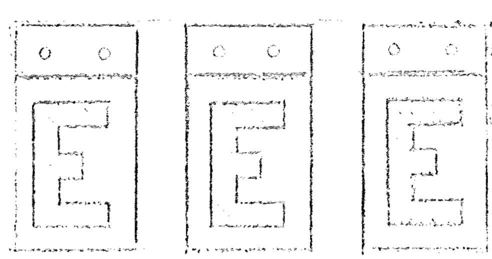
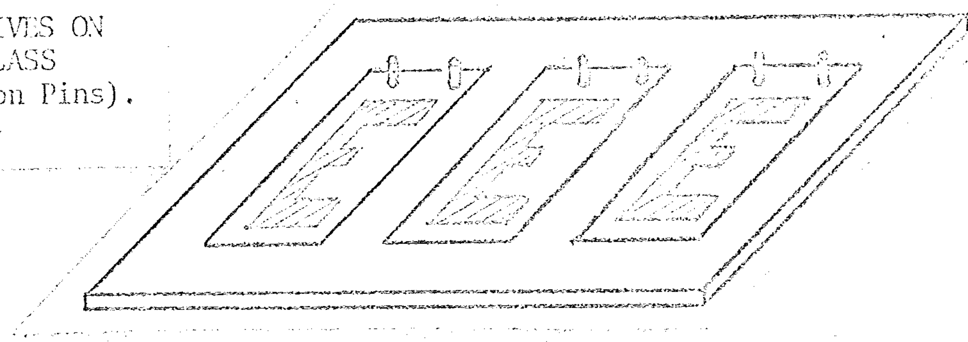


FIGURE 2- (CONTINUED)

(e) MOUNT REGISTERED POSITIVES ON SPECIAL FILM CARRIER GLASS (Provided with Precision Pins). INSERT GLASS IN VIEWER.



9.1.5 Pre-Registration Concept Summary

9.1.5.1 System Approach to Multiband Viewing

If we consider the multiband viewing requirements from the input to the output on a system basis, rather than a component hardware basis, we have to define the inputs more specifically. For example, the output of the Experiment S101 Multispectral Terrain Photography, will be six 70mm x 100 foot long negative film rolls. Four of these are intended for usage in the PMV, two Kodak Panatomic-X Aerial films and two Kodak Infrared Aerographic films. It is also considered that the original negatives will not be used in the PMV and that positive dupes will be prepared for usage in the PMV by the earth resources user agencies and Prinicpal Investigators. It is at this early stage in the utilization of the multiband data wherein anticipation of future problems and effort can provide maximum effective usefulness.

9.1.5.2 Film Duplication

It is considered that the original negatives will be treated like "gold" and that just a limited number of first generation positives ("masters") will be made from the original negatives in order to preserve their quality. It is also considered that second generation positives will be prepared from the relatively few first generation positive "masters" and that these second generation positives represent the highest quality imagery which will be used in the PMV. These second generation positives will undergo significant handling and manipulating as they are used in the PMV since almost each set of frames must first be precisely registered and superimposed in order for effective screening and precision analysis to occur.

9.1.5.3 Pre-Registration Concept with Pre-Registration Printer

The Pre-registration concept, originally introduced in Section 1.2, would start with the first generation positive "masters" however, instead of making straightforward dupes of the "masters" for usage in the PMV, it institutes the Pre-Registration Printer for preparing the film roll to be used in the PMV. The Pre-Registration Printer would contain all the precision adjustments and capabilities of the PMV with respect to the transporting and registration of the film frames. The objective is to reproduce the imagery of the four (4) 70mm x 100 foot film rolls on to one (1) 9 1/2" x approximately 300 foot film roll with all four (4) frames of a specific area imaged in the exactly desired locations for automatic registration in a simpler multiband viewer. Since there are no spectral filters involved, no multiple magnifications, desaturation, etc., the Pre-Registration Printer is significantly simpler than the PMV and its optical projection system can utilize a single lens with beam splitters to eliminate differential distortion and focal length. The output of this Pre-Registration Printer, the 9 1/2" wide film roll can then be utilized in a "Simplified" Precision Multiband Viewer. Figure 9.3 illustrates the Flow Diagram for Multiband Viewing for both the regular concept and the pre-registration concept.

9.1.5.4 Conclusions and Recommendations

The primary effort of this study has been to be completely responsive to the requirements of Exhibit "A", Statement of Work for "Precision Multiband Viewer Study", Contract NAS9-9489. To accomplish this a minimum of effort was available for presenting the advantages of the Pre-Registration Concept. Therefore, it is recommended that further study be conducted

KEUFFEL & ESSER CO.

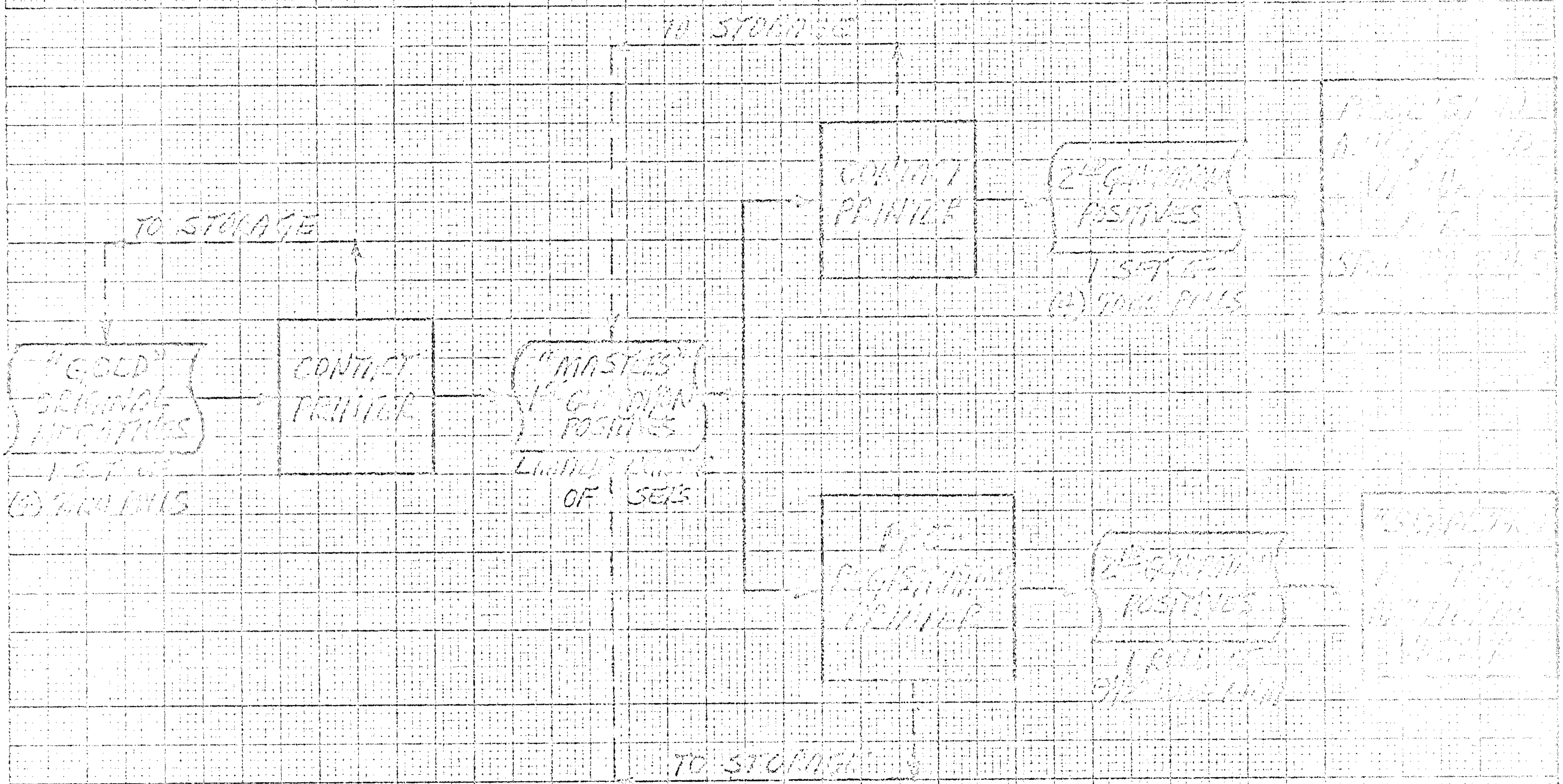


FIGURE 9.3 - FLOW DIAGRAM FOR [illegible]

to further analyze the Pre-Registration Concept and that a breadbroad model be constructed to demonstrate the feasibility of this concept.

9.2 Overlay and Annotation Capability

9.2.1 General

The requirement for achieving an overlay capability on the MPV screen for annotations has been studied and is considered to be a secondary objective or performance feature, relative to the primary objective of superimposing the four spectral images and of varying the hue, intensity and saturation of the resultant image. It is evident that the functions of screening and precision analysis of multiband photographic imagery should not be minimized in order to enhance the overlay and annotation function. Therefore, the configuration defined in the study utilizes a nearly vertical projection screen for conveninece in viewing rather than annotation. It is felt that transparent overlay material can be easily affixed to this projection screen and direct annotations can be appropriately made with the porous nylon tipped marking pen or equivalent. For those users of the PMV with heavy planimetric compiling needs a table top projection screen would certainly be more convenient. But then again, in order to do effective compiling, a greater range of projection magnification (continuously variable) is also desired. It readily becomes evident that an optimized overlay and annotation capability for the PMV would impose objectionable design parameters relative to the projection optics with associated registration and illumination complexity as well as the decreased human engineering criteria and convenience in viewing with respect to horizontal versus vertical viewing configurations.

9.2.2 Remote Pantograph or X-Y Plotter Capability

A useful annotation capability can be combined with the vertical viewing configuration by the addition of auxilary equipment modules which can be incorporated on to the PMV, or not, in accordance with the user's needs. There is a wide variety of standard off-the-shelf devices which can be employed to implement this annotation function.

9.2.2.1 Remote Pantograph Device

Standard pantograph mechanisms offer the advantage of remoting the annotation and/or overlay material as well as the capability for scale changing so that the projection optics are not complicated with unnecessarily stringent requirements. It would only be necessary for the stylus, which is mechanically coupled to the annotation pen, to be located at the projection screen. Manipulation of the stylus over the projected imagery would trace and define the subject on the annotation sheet at the desired scale factor.

9.2.2.2 Direct Plotting at Projection Screen

A simple open-loop analog X-Y Plotter can be incorporated over the projection screen to facilitate annotation on the nearly vertical overlay sheet. Instead of the analyst having to trace and annotate on to the overlay in an uncomfortable "blackboard" writing fashion, he would merely have to actuate a 2-axis joystick control. This joystick control could be conveniently located on the work table for easy operation and implementation. The 15" square screen size is compatible with the size of many of the standard plotters. For most cases, the overlay could be simply clamped on to the screen. Where greater accuracy is required, flattening techniques employing vacuum or vacuum or electrostatics can be employed.

9.2.2.3 Remote Plotting and Automation

Remote plotting, on to map sheets, charts or any other desired document, can be implemented with either analog or digital plotters. In this case only the stylus or a reticle, as desired, needs to be located at the projection screen with its position information transmitted to the remotely located plotting module via closed-loop servo systems. Again, depending upon the needs and requirements of the users; coverage, scale changing, speed, accuracy, characters and symbols to be annotated, storage, interface with computer data, etc., can all be accomplished within the modular or building block framework. Eventually, automation and interface with digital data processing systems will be required of the PMV. Eventually, mensuration capabilities will be required and rapid correlation and reduction of the multiband data will be essential.

However, since the scope of the present PMV, as defined by the Work Statement, is the screening and precision analysis of multiband photographic imagery, this overlay and annotation capability is most practically accomplished by hand.